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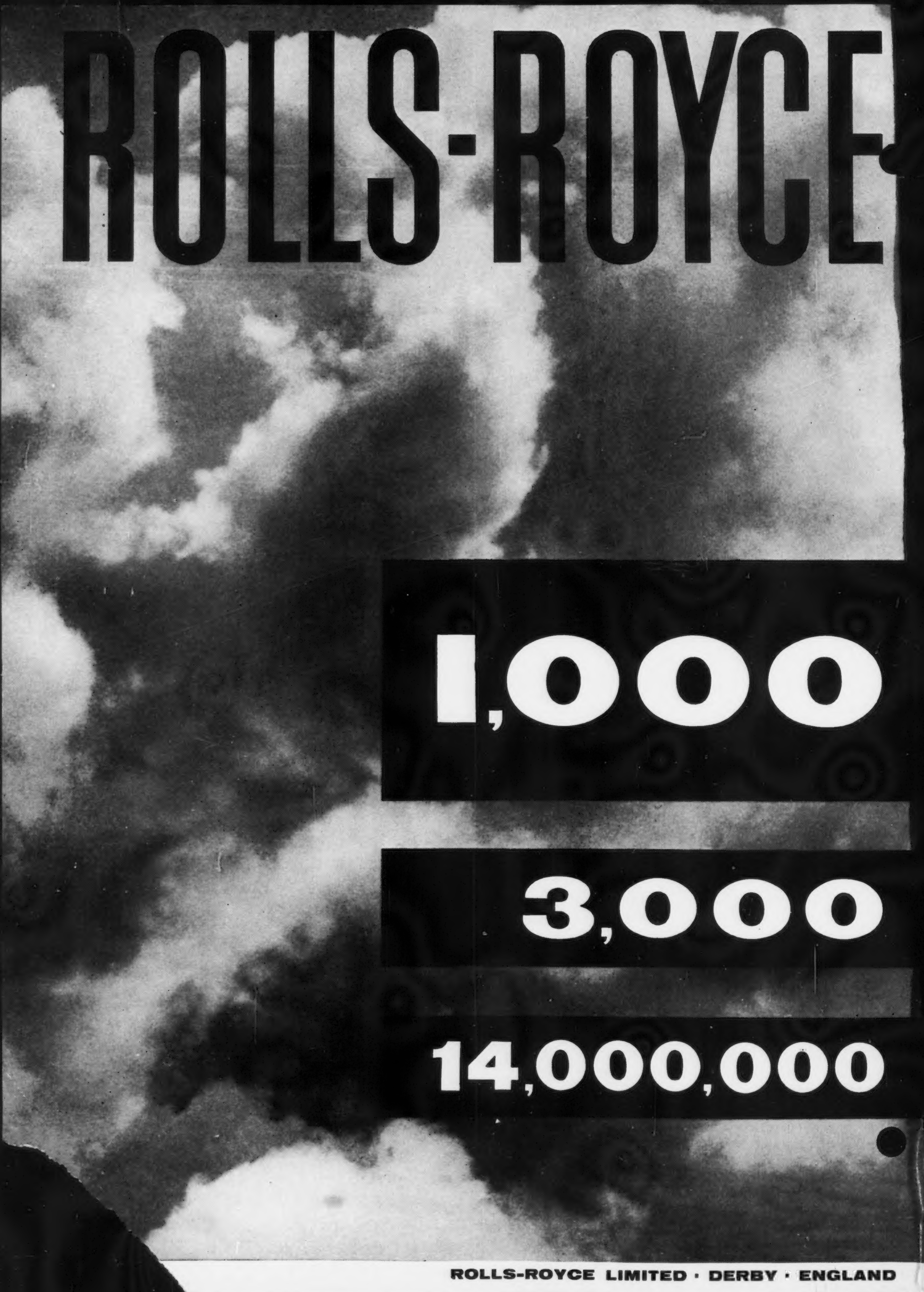
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CANADAIR FORTY FOUR

Canadair Forty Four freighter, powered by four Rolls-Royce Tyne, twin-spool turboprop engines, with the unique feature of a hinged tail section, which swings aside for straight-in loading and unloading of cargo. **(See page 2)**

EDITORIAL

DISMANTLEABILITY

Technical journals, company periodicals, manufacturers' brochures and trade magazines shower upon us nowadays in an overwhelming profusion and, though many of them contain items that we should like to keep, we seldom have the space to store this abundant literature. Certainly we keep a few pet publications – some of us even have them bound, which not only helps to prevent their getting dog-eared but reduces their bulk on the shelf. But we have to throw a great deal away, sometimes after tearing out the bits that are of particular interest; and these bits are preserved for future reference in our personal files.

With this issue of the Canadian Aeronautical Journal we have introduced some changes, designed to enhance its "dismantleability" without affecting its "bindability". As we suggested last April, the cumulative value of the monthly issues of the Journal is considerable and it would be wise to keep all of them and to have them bound as each Volume is completed. But this is not always practicable and the next best thing is to extract and retain only those papers in which one is particularly interested. The membership of the Institute covers a very wide range of interests and, for this reason, each issue of the Journal must contain papers on a variety of subjects. Perhaps only one or two papers a year will be of direct value to any one reader; and a few others may be of lesser value to him, but worth keeping for a while. To provide the flexibility necessary to suit all tastes, the Journal is now arranged so that any paper can be extracted without interfering with adjacent papers, simply by removing the staples and using a paper-knife along the back (preferably one sheet at a time). A filing margin is provided; and even holes, suitable for the standard 3-ring binder.

In time we hope to extend this principle to the advertising. We believe that advertisements in the form of catalogue sheets, data sheets, performance curves and other technical material, rather than the more normal display advertising, would render a most welcome service to our readers, without losing any of their advertising effect. Like the technical papers, they would be extracted and filed for reference – even by those who have their volumes bound and, in so doing, would otherwise throw the advertisements away. By a little collecting from issue to issue, it will be possible to build up a personal library of such specifications and trade literature.

These innovations will enable us to publish, in one publication, a wider diversity of papers, from the scientific to the practical, than has been acceptable in the past, since these sometimes quarrelsome bedfellows can now get out of bed. Yet we are not going all the way to a Journal in loose-leaf form and those who want to keep their copies intact can still do so. In brief, we believe that the introduction of "dismantleability" will result in a more useful publication to working engineers.

CANADAIR FORTY FOUR

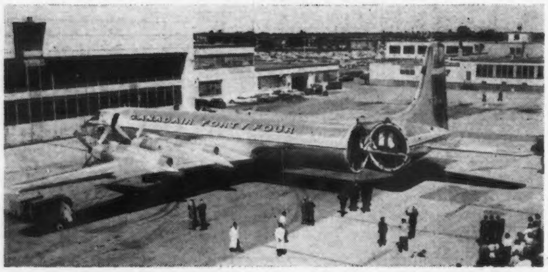
COMMERCIAL cargo airline requirements for straight-in loading are met with the swing-tail layout of the Canadair Forty Four turboprop freighter. Use of this feature, in conjunction with mechanized loading, gives an aircraft ground turn-around time of one hour, compared with five hours for conventional piece loading.

The swing-tail, which can be opened through an arc of 105° in about 90 seconds and closed and locked in the same amount of time, is mounted on two hinges on the starboard side. The actuators which operate the tail are located in the dorsal fin and consist of two, interconnected, articulated hydraulic jacks, capable of a 12,000 lb operating force. Collet-type locks are incorporated at both ends of the forward jack and at the extended end of the aft jack. The jacks can be locked in both the open and closed positions. The actuating system is designed to open or close the tail against a 30 mph cross-wind and to hold it open against a 60 mph wind.

Eight locks secure the tail section to the main fuselage. These are hydraulically operated and of fail-safe design; however, in the event that one lock should fail, the full design loads can be carried by the adjacent locks. The lock itself consists of a tongue fitting on the main fuselage which engages with a fork fitting in the tail. The lock pin engages and is locked hydraulically. Eight identical hydraulic actuators are installed with their piston rods directly connected to the sliding lock pins. Internal mechanical locks, which operate when the actuators are extended, are incorporated to provide a second source of locking pin security. In addition, spring loaded ball locks hold the lock pins in the extended position.

During the closing sequence, alignment between the tail and fuselage joint is obtained by a ramp and roller system. Final alignment is provided by wedge blocks mating with recesses next to each lock. An inflatable seal around the joint faces maintains cabin pressure and a weather seal prevents entry of rain when the airplane is unpressurized on the ground.

Opened swing-tail showing actuator in the extended position and hinge fairings



Canadair Forty Four turboprop freighter

To insure that unlocking cannot be selected in flight, a manual quick-disconnect in the hydraulic pressure supply line at the swing-tail joint isolates the swing-tail hydraulic installation. An indicator in the cockpit shows if the tail is open and operates when one or more lock pins are not engaged or when the hydraulic pressure supply line at the swing-tail joint is not disconnected.

Hydraulic pressure for the swinging actuators and the locking actuators is provided by an auxiliary, electrically driven pump installed in the fuselage on the port side of the forward underfloor compartment. This pump, which can also provide hydraulic pressure for all hydraulic system functions, has its suction line connected to the main hydraulic system reservoir and its pressure line connected to the system control panel. The swing-tail can also be operated by either the engine-driven pumps or the hand pump in the main hydraulic system.

In the operation of the swing-tail, a control panel is located inside the tail section next to the joint. This panel has a toggle switch which combines "open-closed" operation for the tail section and "on-off" control for the auxiliary hydraulic pump. Also on it are "unlocked", "open" and "open and locked" indicator lights.

Controls for the elevator, rudder and elevator trim pass across the fuselage break-line and are designed so that, in disconnecting and reconnecting, the correct relationship between the pilot's controls and the respective surface controls is maintained.

Continuity of the control system is provided by sets of bevel gearboxes which operate pushrods through bell-crank levers. These gearboxes convert rotary motion of the control torque tubes into fore and aft movement across the break-line, where it is converted back into rotary motion by a second set of gearboxes. The pushrod ends are set so that the linkage is in slight compression, eliminating backlash.

Hydraulic pressure and return lines for the swing-tail system and the hydraulic lines for the control surface locks are carried across the break by means of rotating swivel joints. Flexible harnesses and hoses are used across the break for the electrical power lines and for the pneumatic and fuel lines to the tail anti-icing heater.

MODERN CARGO AIRCRAFT DESIGN†

by E. H. Higgins,* F.C.A.I.

Canadair Limited

INTRODUCTION

The title "Modern Cargo Aircraft Design" which was assigned to this paper, well before the time it was prepared, is obviously somewhat rather ambitious. Therefore rather than attempt to cover a broad area of Cargo Aircraft Design considerations, I have selected two factors which are particularly significant to both the cargo aircraft designer and the operator and will try to discuss these in sufficient detail to outline the general methods of analysis which can be applied and then indicate some conclusions.

These factors are Cargo Density and Cargo Handling.

DEFINITION OF THE PAYLOAD

One of the first and most important factors which must be established before proceeding with the design of any airplane is the definition of its payload. The difficulties which exist in defining and providing for the commercial cargo payload may be illustrated by comparing the cargo variables with the well-defined aircraft payload known as the passenger.

Because human cargo demands such fringe benefits as closely controlled, draft-free air conditioning, food and drink, individual lighting, low noise levels and similar concessions to his comfort and boredom, it might be expected that the designer and operator of all-cargo aircraft would find their task to be relatively straight forward. On the other hand, the passenger, as an item of cargo, is a remarkably adaptable and cooperative package. It takes itself from its point of origin out to the airport, at its own expense, sorts itself out at the terminal according to destination, loads itself on board the aircraft, packs itself into a standard container and lashes itself down. On arrival at its destination the cargo detaches its tie-down fittings, removes itself from its container, unloads itself from the aircraft and finally delivers itself at its own expense from the airport to its point of intended delivery.

The most important single feature of the human cargo is its high degree of standardization. Excluding smaller children, who form a very small proportion of total revenue traffic, the weight of the article varies from approximately 100 lb to 250 lb, a range of 2.5-1. The length of the article is somewhere between 4.5 ft and 6.5 ft, width from 14 to 22 inches and the item is so flexible and elastic that despite dimensional variations of as much as 100% they can all be packed into a single size container. Most remarkakble of all is that the density of the item remains virtually constant.

The variations in general air cargo are a different story. Item weights can cover a range of from 1 lb to 10,000 lb or 1,000,000% variation. Dimensions vary from 1 inch to over 100 inches in all directions or 10,000%. Provisions for creature comforts, incidentally, cannot be eliminated from the cargo aircraft design and must be adequate for everything from baby chicks to horses.

CARGO DENSITY

Of greatest concern to the cargo aircraft designer however, is the wide range of densities which in current operations varies all the way from 2 to 100 lb/cu ft with significant volumes over the range of 3 to 24 lb/cu ft.

Three major US airlines have each conducted a limited sampling of cargo density carried in their cargo operations. The *average* densities reported by these sources were 10.2, 11.2 and 13.9 lb/cu ft as received in the warehouse.

The most extensive survey and analysis of densities in all cargo operations, which has come to our attention, was conducted by the Rand Corporation for the USAF[1]. The data in this report were derived from actual measurement and weighing of all cargo carried by MATS to the Pacific area during a twelve month period ending in April 1956. The average density, during this survey, turned out to be 13.1 lb/cu ft.

Unfortunately, for the cargo aircraft designer, this variation in average densities of some 40% is likely to be a continuing fact. The density of cargo offered will always be strongly influenced by three factors:

(1) *The routes under consideration*

Traffic through Detroit, for example has a relatively high density because of the large volume of automotive parts offered.

(2) *The tariff structure applied by the airlines*

Because, as will be shown later, aircraft cargo volume is itself an expensive commodity, there will be more incentive to scale tariffs according to density, with the lowest density cargo being charged the highest tariff. At the other end of the scale, very high density cargo may be carried at rates as low as 5 or 6c/ton mile. In the case of a modern cargo aircraft, such rates will provide a revenue in excess of the Direct Operating Cost and, at the same time, ensure that high operating load factors are not precluded by volume limitations.

(3) *The tariff structure of competing forms of transportation*

The trucking and shipping industries will not stand idly by and watch the gradual diversion of their traffic

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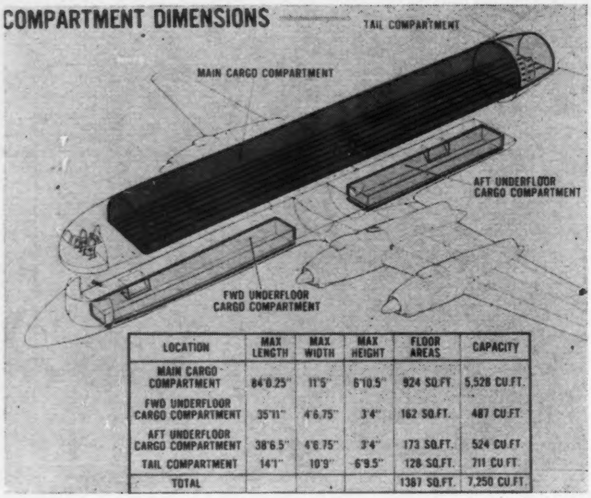
†Paper read at the Annual General Meeting of the C.A.I. in Ottawa on the 25th May, 1960.

*Chief Engineer – Aircraft



LOCATION	MAX LENGTH	MAX WIDTH	MAX HEIGHT	FLOOR AREAS	CAPACITY
MAIN CARGO COMPARTMENT	84'0.25"	11'5"	6'10.5"	924 SQ.FT.	5,528 CU.FT.
FWD UNDERFLOOR CARGO COMPARTMENT	35'11"	4'6.75"	3'4"	162 SQ.FT.	487 CU.FT.
AFT UNDERFLOOR CARGO COMPARTMENT	38'6.5"	4'6.75"	3'4"	173 SQ.FT.	524 CU.FT.
TAIL COMPARTMENT	14'1"	10'9"	6'9.5"	128 SQ.FT.	711 CU.FT.
TOTAL				1387 SQ.FT.	7,250 CU.FT.

Figure 1
CL-44 dimensions and capacities

to the airlines even though the maximum volume of surface transportation which could be absorbed by the airlines during the present decade could not be much more than a measly 1%, which incidentally would require 500 new aircraft with the capacity of the CL-44.

Now it has often been suggested by aircraft manufacturers, who are proposing cargo aircraft which are, at best, marginal in usable volume, that there is no reason for concern because:

(1) The modern cargo aircraft will permit present air cargo rates to be cut almost in half; which is true.
(2) This will attract new traffic from surface transportation; which is true.
(3) Average densities in the trucking industry run around 17 lb/cu ft and in the shipping industry around 30 lb/cu ft; which is true.
(4) Therefore the average densities carried by the modern cargo aircraft will be higher than in the past; which is not necessarily true. Even a cursory examination of present tariffs offered by surface transportation shows that the items of cargo which are carried at rates which can be matched by the modern aircraft have densities which are in the same range as the present air cargo traffic. The only factor which will tend to raise the average density of air cargo will be the application of rates for certain high density items which are lower than the average total operating cost. As mentioned previously, we believe this will be done but it can only be applied to a small proportion of the total cargo carried if the airline is going to have a profitable operation.

Well then, what average cargo density should the aircraft designer assume? Canadair is in the early stages of a Market Research Program which is directed toward identifying the specific items of cargo which can be expected to be carried economically in both domestic and international operations when modern cargo aircraft are introduced. Among other things, this survey will establish the potential volume, routing and density of each item of cargo so identified. This is an almost staggering task which in just one early stage of analysis involved over 400,000 IBM cards which weighed one ton. By the end of this year we expect to be in a position to speak with more authority. My answer today, based on all the information which we have, is that the average *warehouse* density should be assumed to be 13 lb/cu ft.

Having established the average density of cargo as received in the warehouse, two important stages of analysis are required to determine realistically the average payload which can be accommodated in a particular aircraft.

(1) Determine the actual volume of cargo which can be loaded in the airplane, and
(2) Determine the effect of *variation* of cargo density on the probable load factor which will be achieved.

It has been common practice in the past to suggest that the average cargo density which can be accommodated in an aircraft is equal to the maximum weight-limited payload divided by the gross volume of the cargo compartments within the interior lining. In practice, the average density of cargo required to achieve 100% load factor will be at least 40% higher than this figure.

This can best be illustrated by an analysis of the CL-44-D4 aircraft as it will be operated by the US all-cargo carriers.

From Figure 1 it will be seen that the total volume within the inside lining of the four cargo compartments is 7,250 cu ft. The maximum net payload is 63,000 lb so that the average density of cargo which can be carried would apparently be 63,000/7,250 = 8.69 lb/cu ft.

Now, it will be shown later that use of pre-loaded pallets and containers, combined with mechanized loading, is essential for an efficient cargo operation.

Accordingly, it follows that average cargo densities which are related to gross volume in the airplane no longer have any meaning. The total usable volume in the airplane is that which can be contained within the inside dimensions of the pallet and net envelopes and the bin envelopes.

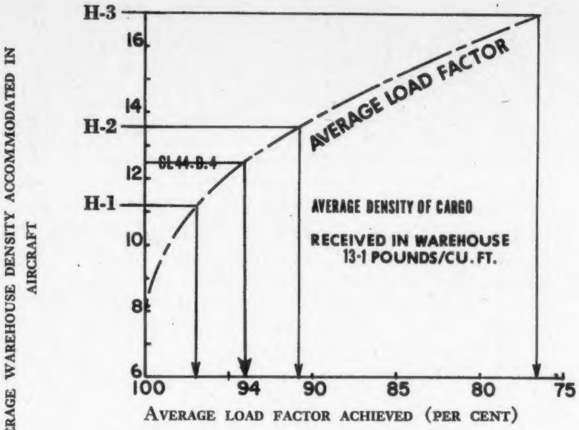
It will be seen from Table 1 that the true usable

TABLE 1
USABLE GROSS VOLUME WITHIN PALLET AND BIN ENVELOPES

	Cubic Feet
Main cargo compartment (10 pallets 91ft–11 in by 7 ft–5 in)	4,285
Forward main (bulk loading adjacent to forward cargo door)	363
Hinged tail (bulk loading exclusive of space reserved for hinge inspection)	551
Forward underfloor (bulk loading)	487
Aft underfloor (4 bins 8 ft–7 in long)	400
Total usable volume	6,086
Net Volume Utilized	
Stacking efficiencies: 85% in containers, 75% in bulk.	
Pallet and bin volume 4,685 × 0.85	3,982
Bulk loading volume 1,401 × 0.75	1,051
Net warehouse volume utilized	5,033

Total cargo weight: 63,000 pounds

$$\text{Average warehouse density accommodated} = \frac{63{,}000}{5{,}033} = 12.5 \text{ lb/cu ft}$$



BASED ON USABLE CARGO SPACE, NET OF AISLE SPACE, CLEARANCES, AND AVERAGE CLEARANCES, AND AVERAGE SPACE LOSSES FOR STACKING AND TYING DOWN CARGO.

Figure 2
Estimated load factor achieved[1]

volume of the CL-44-D4 is 6,086 cu ft, or approximately 85% of the gross volume. In determining the warehouse volume which can be accommodated within this usable volume, a further reduction must occur to account for stacking efficiency. Based on stacking tests conducted by an all-cargo airline using Canadair's standard 10 ft × 7.5 ft pallet and actual items of cargo as received in the warehouse, it has been determined that a stacking efficiency of 85% can be achieved in practice. For bulk loaded areas, it has been found that the stacking efficiency will average 75%.

The final step in predicting the average load factor which can be achieved in practice is to analyze the effect of *variation* in warehouse densities. It is obvious that if the *average* density of cargo received in the warehouse is 12.5 lb/cu ft and the *average* density which the aircraft will accommodate is 12.5 lb/cu ft, then the airplane will be volume-limited 50% of the time.

The effect of variation in cargo density has been considered in detail by Mr. R. E. Bickner in the Rand Corporation Research Memorandum[1] mentioned previously and I will not repeat or attempt to improve on this excellent analysis.

Figure 2 shows the effect of density variation on average load factor as derived by Mr. Bickner and, although it is based on the variation in cargo densities found in the MATS survey, the general shape of the density versus frequency of occurrence curve is similar to that reported by commercial cargo operators. It will be seen that, despite the fact that the average density of 12.5 lb/cu ft which can be accommodated in the CL-44 is less than the average warehouse density of 13.1 lb/cu ft in the Rand survey, the estimated average load factor cannot be expected to exceed 94%. If the usable volume were reduced further to say a design density of 16 lb/cu ft, then the probable average load factor achieved would be just over 80%. These estimates, by the way, are based on the assumption that there is always a sufficient number of pounds of cargo waiting in the warehouse to provide a 100% load factor if it could be squeezed into the available space.

The apparent conclusion at this point would be that the more volume provided in the airplane the more money it will earn. The other side of the coin is, of course, that increased volume also results in cost penalties. First because weight and drag reduce the design payload, the added drag reduces block speed and taken together the productivity capability of the aircraft will be reduced.

The task of the cargo aircraft designer, therefore, is to determine the correct compromise between volume limitations on one side and weight and drag penalties on the other side, which will result in the optimum efficiency and profit potential for a given route.

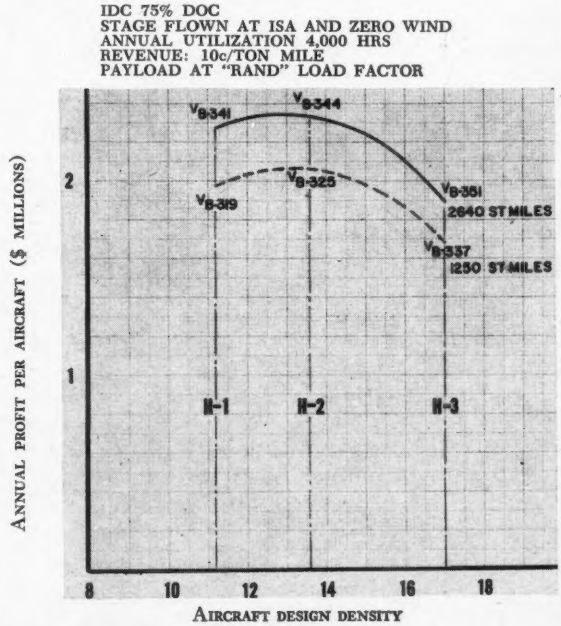
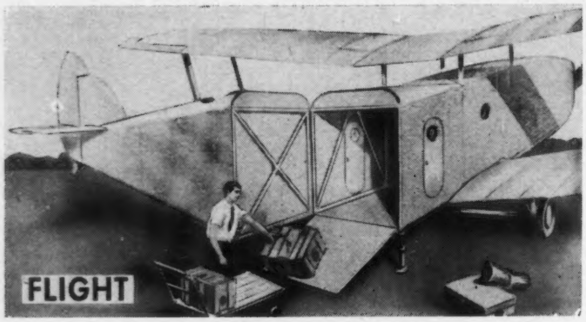


Figure 3
Annual profit per airplane vs design density

TABLE 2
TABULAR COMPARISON H-1, H-2 AND H-3.

	H-1	H-2	H-3
Takeoff weight	260,000	259,110	258,400
Fuel load including reserves	65,500	64,610	63,900
Average cruise speed (mph)	361	366	370
Maximum payload	90,500	95,900	101,200
Usable cargo volume (cu ft)	8,100	7,030	5,970
Net cargo density accommodated	11.2	13.6	17.0
RAND estimated load factor achieved	97.0	90.7	76.7
RAND probable average payload	87,800	87,000	77,600
Block speed with average payload (mph)	341	344	351

To illustrate the method of arriving at the optimum cargo volume for a given route, we have analyzed three hypothetical aircraft all of which are designed to carry their maximum weight-limited payload from New York to San Francisco against 70% probability winter head winds. The first aircraft, designated CL-44 H-1, has a cargo compartment length of 105.5 ft, the second, CL-44 H-2, a length of 90.5 ft and the third, CL-44 H-3, 75.5 ft. The only difference between the three aircraft is the length of cargo compartment and consequently the volume (Table 2 and Figure 3).



The 1922 Gloster "Goods Carrying" aircraft designed by Mr. H. P. Folland. Its goods load was 1,600 lb; cruising speed, 92 mph; engine, a 360 hp Rolls-Royce Eagle.

Figure 4
Gloster swing-tail

FLIGHT October 8, 1925

It is now several years ago that Mr. H. P. Folland, of the Gloucestershire Aircraft Company, designed a goods-carrier in which the rear portion of the fuselage was hinged and when swung outwards exposed the total cross-sectional area of the fuselage for the loading and unloading of goods. Hitherto the idea has not been taken up, but it is obvious that it would be a very great advantage to be able to load bulky goods in this fashion, and the time has now certainly come when some such type should be given more serious consideration.

Figure 5
Gloster swing-tail excerpt from 1925 *Flight*

The next step in the analysis was to calculate the Direct Operating Cost for each aircraft, apply overhead costs and determine total operating costs. Total annual revenue was calculated on the basis of 10c/ton mile average and we were then in a position to compare the profit potential of the three aircraft on the New York-San Francisco route.

The results of this analysis (Figure 3) indicate that the most efficient airplane will have a design density capability approximately equal to the average density of the cargo which is expected to be carried.

It must be emphasized, once more, that this conclusion is valid only on the assumption that there is always available for shipment sufficient pounds of cargo to fill the available volume in the airplane. It would be more realistic to expect that the pounds of cargo available, on the average, was equal to say 80% of the maximum weight-limited payload. The analysis should then be modified to reflect the variation on a probability basis of both the total weight of cargo available for a flight in addition to the variation of average density of the cargo available on each flight.

This final step in our analysis has not been completed in time to include in this paper but the effect will obviously be to shift the curve to the right and show that the most efficient design density will be somewhat higher than the expected average density of cargo as received in the warehouse.

CARGO HANDLING

The second subject of particular interest to the cargo aircraft designer is the mechanization of cargo handling and its effect on operating costs and operating revenues.

The aircraft is just one element of the cargo transport system and the efficiency of the vehicle cannot be properly evaluated except in conjunction with the cargo handling equipment both in the airplane and on the ground.

Just how much weight penalty and cost penalty is warranted to provide a mechanical loading system? Is it really worth while or just fashionable?

Well I will show by a simplified analysis of the D-4 and its system how this question may be answered. Let us first describe the system which will be in operation next year with the CL-44 operators and then analyze its probable effect on the airlines' profit-making potential.

As a starting point, it was first established by a careful analysis that a turn-around time of 5 hours would be required to unload and reload the maximum payload of 65,000 lb using conventional hand loading methods.

The design objective established for our mechanized loading system was to ensure a turn-around time of 1 hour from the time the aircraft taxied in to the warehouse ramp until it taxied out again. The time allotted for the actual unloading and loading a complete payload was 45 minutes.

Our initial studies for the aircraft system followed the general pattern of a rigid pallet riding on a roller bed in the aircraft floor. However, we soon discovered that this approach involved a weight penalty of almost 10% of payload and a cube loss, due to the depth of the rollers and pallet alone, of over 300 cu ft.

It was decided therefore, to try an entirely new approach based on a lightweight flexible pallet riding on rubbing strips instead of rollers and pulled into or out of the main cargo compartment by a chain drive running along each side of the floor.

We have since demonstrated the feasibility of this concept in our full scale functional test rig. The system has been accepted by all three of our commercial customers and is now in production.

As a matter of interest we have often been questioned about the origin of the swing-tail. We knew the idea had been generally discussed in the industry since the end of World War II but after a little historical research we were surprised to discover that the concept goes back at least 38 years (Figure 4).

Three years after the original proposal *Flight* Magazine was becoming somewhat impatient (Figure 5) at the delay in applying what was obviously an excellent idea to a production aircraft. As it turned out, they only had another 35 years to wait.

Figure 6 shows the arrangement of our tie-down rails in the main compartment. The six rails are flush with the floor surface, are spaced 20 inches apart and incorporate sockets for tie-down fittings at 2 inch intervals over the whole length of the compartment.

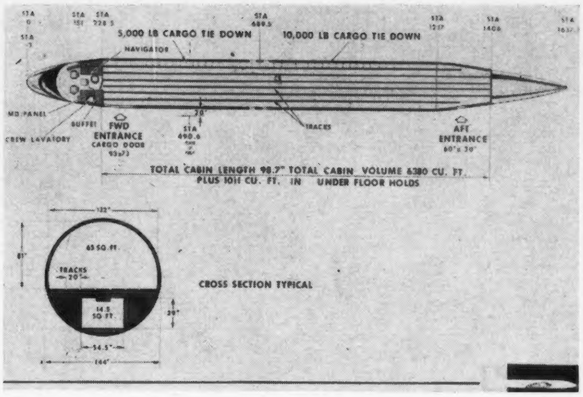
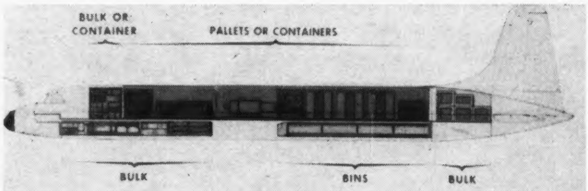


Figure 6
Plan view of main compartment floor



WEIGHTS OF AIRBORNE CARGO HANDLING ITEMS

10 PALLETS AT 140 LB	1400			
10 PALLETS AT 170 LB (FENCE)		1700		
10 PALLETS AT 170 LB (DOGHOUSE)			1700	
10 CONTAINERS AT 400 LB				4000
BARRIER NETS AND TIE-DOWN FITTINGS	820	770	820	200
WINCH MECHANISM (4000 LB PULL)	280	280	280	280
4 BINS AT 150 LB	600	600	600	600
TOTAL WEIGHT IN LB	3100	3350	3400	5080

Figure 7
Inboard profile D-4 cargo system

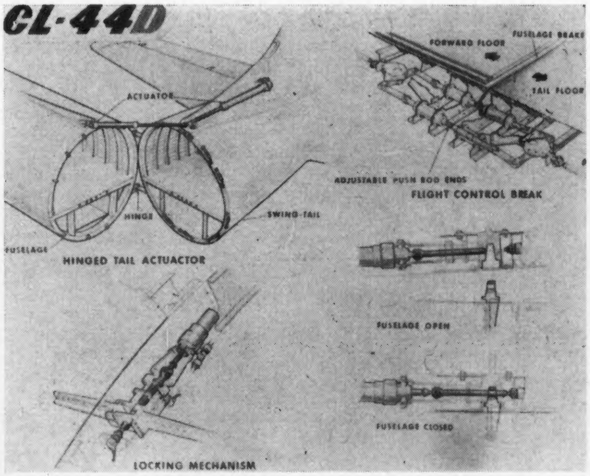


Figure 8
Swing-tail details

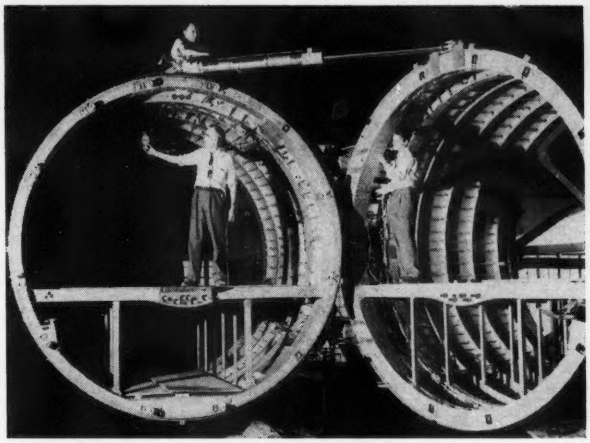


Figure 9
Swing-tail functional test rig

Figure 7 shows the typical arrangement of pallets and containers which has been assumed for our cost analysis. The main compartment is filled with palletized units. Four bin containers are end loaded into the aft lower compartment and the forward underfloor compartment and tail compartment are assumed to be piece loaded. Incidentally, we believe that hand loading the lower forward compartment may be the most critical element in our turn-around time and we are developing a semi-mechanized bin loading arrangement for this area.

Figure 8 is an illustration of our swing-tail arrangement showing the operating jack at the top and details of the eight hydraulically operated lock pins and the flight control transmission system across the swing-tail break.

Figure 9 illustrates our full-scale functional test rig for the swing-tail, which has successfully completed 10,000 cycles of operation under design load conditions.

Our flexible pallet, shown in Figure 10, is of metal-faced plywood construction approximately ⅜ inch thick with aluminum-alloy rubbing strips bonded to the bottom surface. These strips ride on matching strips on the aircraft floor made from extruded nylon impregnated with a dry lubricant. The side edges of the pallet are fitted with net attachment fittings and guide rollers

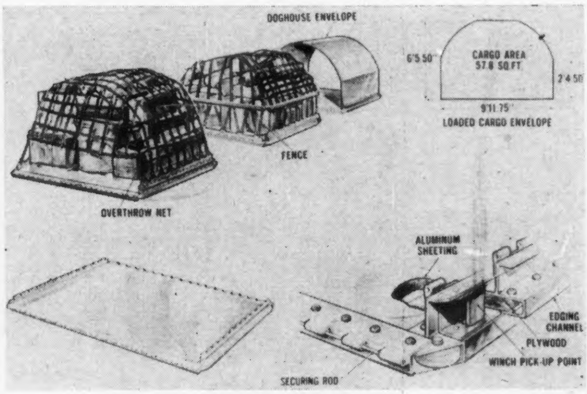


Figure 10
Light pallet and net

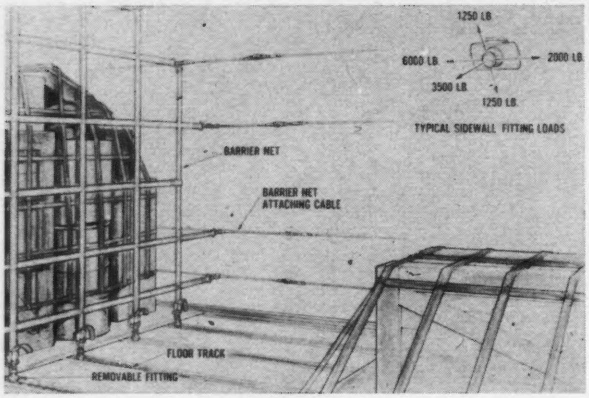


Figure 11
Crash net installation

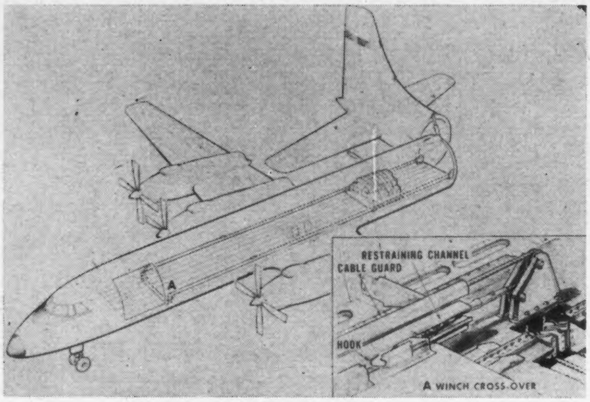


Figure 13
Winching mechanism

which engage the overlapping guide rails along each side of the aircraft floor.

This pallet, with a load capacity of 8,000 lb, weighs only 140 lb and the dacron throw-over net just 18 lb. This is roughly half the weight of a rigid pallet design.

Negative g flight loads and design side loads are transmitted from the throw-over net to the side rails and we have completed tests which have demonstrated that deflections under both these conditions will not foul the aircraft structure.

Figure 11 illustrates the installation of our barrier nets which are designed to take the 9 g forward crash loads. They are attached to longitudinal straps along the sides of the fuselage and to the 6 tie-down rails in the aircraft floor. These nets weigh less than 20 lb each. They are interchangeable and can be attached or detached in less than 45 seconds. As you will see later, they are normally carried into position on the back face of each pallet load.

For highly concentrated loads such as machine tools or jet engines, a special rigid pallet has been designed (Figure 12). Crash load restraint of this pallet is provided by fittings which are installed through cutouts in the pallet base to pick up the tie-down rails in the airplane floor.

The winching system for transferring the palletized loads along the floor of the main compartment consists of a chain drive running along each side of the floor just above the pallet guide rails. The chains are guarded by guide channels. A spring loaded hook attached to the drive chain runs in the lower channel and this hook engages fittings on each side of the pallet (Figure 13). Tests in our functional rig have demonstrated that the pallet loads can be either pulled or pushed by the chain drive system and in fact it has been found that the load can be transferred without difficulty when driven by the chain on one side only.

Figure 14 illustrates the method of loading the bin containers into the aft underfloor compartment. Each bin is approximately 9 ft × 4 ft × 3 ft and rides on rollers on the floor of this compartment. The bins are automatically coupled when they butt together, which enables all four bins to be loaded and unloaded in train.

The remaining essential part of the system, which is just entering the detailed design stage, is the transfer platform at the loading sill. We have studied and discarded a great many configurations for this part of the system and have finally settled on the arrangement which is illustrated in this model (Figure 15). The front end of the platform is attached to the airplane and is designed to follow deflections of the sill in all directions which can be expected, including up and down, sideways and rotation. A simple level switch acts as a sensing device to energize the jack at the rear point of support and move it in a direction which will hold the platform level as the fuselage moves up and down.

The only other piece of equipment required to com-

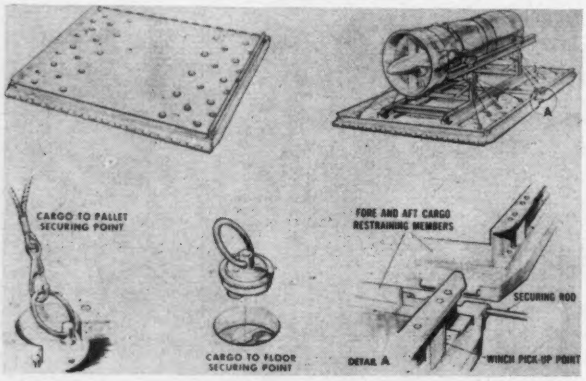


Figure 12
Special pallet

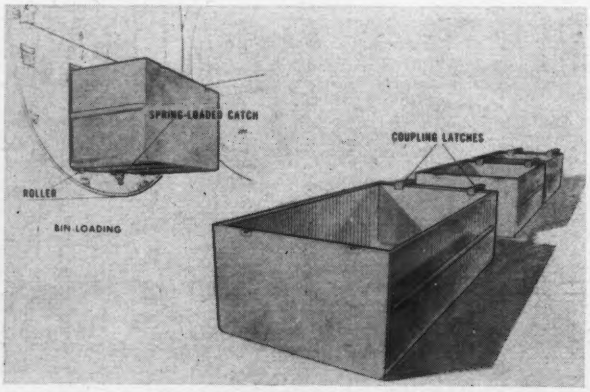


Figure 14
Aft compartment bins

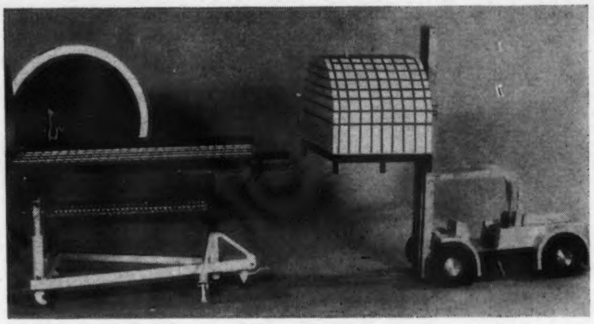


Figure 15
Platform model with load lifted on fork truck

CREW CATEGORY	NO	CARGO AREA	OPERATIONAL FLOW IN MINUTES 0 10 20 30 40 50 60	DECIMAL MANHOURS UNLOAD	LOAD	MISC.	TOTAL
LOAD MASTER	1	GENERAL		.344	.406		.750
WINCH OPERATOR	1	MAIN AFT. UNDER		.283	.333	.134	.750
PALLET HANDLERS	2	MAIN		.567	.667	.266	1.500
FORK LIFT OPER.	1	GENERAL		.321	.379	.050	.750
BULK LOADERS	2	FWD. UNDER		.533	.667	.300	1.500
	2	TAIL		.500	.533	.467	1.500
	2	FRONT MAIN		.600	.733	.167	1.500
TOTAL	11		PRE-LOAD 9 MIN. · UNLOAD AND LOAD 45 MIN. · POST-LOAD 11 MIN.	3148	3718	1384	8·250

LEGEND: UNLOAD ▬ LOAD ▬ REPLACE RAMP CLEAN (ASSUMING 63,000 POUNDS UNLOADED AND REPLACED BY A LOAD OF 63,000 POUNDS)

Figure 16
Loading and unloading manpower analysis

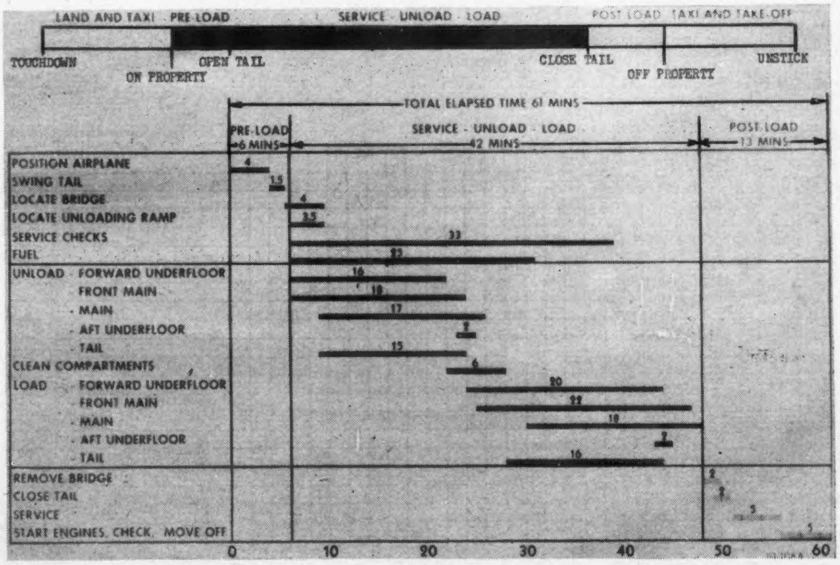


Figure 17
Unloading-loading time sequence

plete the loading system is a standard fork lift of approximately 15,000 lb capacity. The pallet train may be brought to the airplane on dollies. The fork lift is fitted with a roller bed which may be inserted under the dolly beds which are of egg-crate design. When the roller platform is raised the pallet rests on the rollers and when lifted into position at the back of the transfer platform the fork lift bed may be tilted forward until the pallet rolls onto the platform.

The transfer platform will be designed so that it may be carried in the airplane to permit establishing an operation into an unprepared base. The standard fork lift may also be carried in the airplane without difficulty.

Although versions of the transfer platform will be self powered, the basic design concept is to ensure that the entire system can be operated using a standard fork lift as the only essential piece of additional equipment.

We have demonstrated in our rig that an 8,000 lb load can be easily moved along the platform by one man on each side. This includes the case where the load is initially placed on the platform off-centre and cocked to one side. The guide rollers near the four corners of the pallet follow the guide rails which appear as black strips on each side of the platform (Figure 15). These guide rails act as a funnel and bring the pallet into correct alignment with the guide rails in the airplane.

In Figure 16 is shown a manpower analysis derived from time and motion studies for the system which has been described. The total man hours required for loading and unloading the maximum payload has been calculated at 8¼ man hours and this has now largely been substantiated by tests.

In Figure 17 is shown a time sequence analysis based on the same study, which shows a total turn-around time of 61 minutes including unloading, loading, servicing, refueling, swing-tail operation, locating an attachment of the transfer platform and finally engine start, pre-taxi check and taxi away from the warehouse ramp.

Figure 18 shows the pallet load being drawn into position in the airplane. The nylon rub-

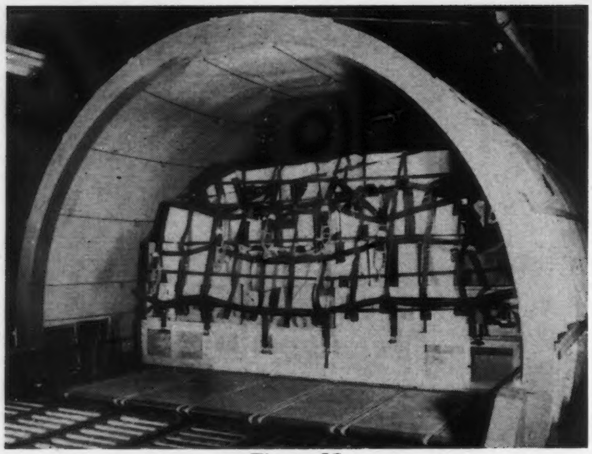


Figure 18
Pallet load moving into position

bing strips may be seen on each side of the tie-down rails on the airplane floor. The crash net for the next pallet load is being carried into the airplane on the back face of the pallet load.

Figure 19 shows the tow hook riding in the lower chain guard channel. The two hook fittings are spring loaded, one end being used to pull the load into the airplane and the second end for withdrawing the load. The hook is manually flipped over from one position to the other by the operator. The open chain which is shown exposed in the test rig will be housed in a similar guide channel in the production system.

We have recently completed 10,000 cycles of operation without failure and with only minor wear on the rubbing strips. During this program sharp silicon sand was applied to the rubbing surfaces every 150 cycles. The coefficient of friction was 0.15 at the start of the program and rose to only 0.17 at the conclusion of the 10,000 cycles.

Table 3 shows the weight breakdown of the cargo handling system in the main compartment. The total weight of this portion of the system was only 2,600 lb and the volume loss less than 1%. Some portions of the system, such as the barrier nets, are required when the airplane is hand loaded. The total weight penalty for the mechanized system including the containers and rollers in the aft underfloor compartment is 2,800 lb and this penalty has been applied to the cost analysis which follows.

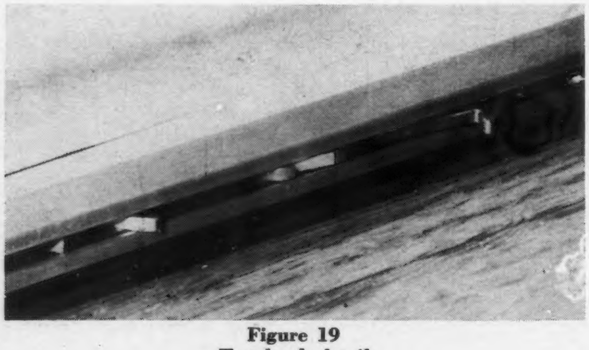


Figure 19
Tow hook detail

COMPARISON OF COST AND REVENUE

For the system which has been described we can now proceed to analyze the cost penalties imposed by the mechanized cargo handling system and compare these penalties against the increased revenue which mechanization will produce.

The cost penalties occur from three sources:

(1) The weight penalty of the airborne system which in this case amounts to 2,800 lb. To make the comparison the least favourable to the mechanized aircraft, we have assumed 100% load factor so that the 2,800 lb loss of payload will apply on every flight.
(2) The depreciation and maintenance cost of the mechanized equipment which has been added directly to the airplane Direct Operating Cost.
(3) Increased cost of spare parts to support the higher utilization which the mechanized aircraft can achieve.

On the credit side, the mechanized aircraft will produce more revenue by spending more hours per year in the air and this higher utilization also reduces Direct Operating Costs by spreading fixed annual charges such as depreciation over a higher number of flight hours.

TABLE 3

MECHANIZED CARGO HANDLING SYSTEM
WEIGHT BREAKDOWN

A. Fixed equipment	lb
Floor panel rubbing strips	80
Guide rails	175
Winching system	295
Total fixed equipment	550
B. Removable equipment	
Longitudinal barrier net attachment straps	215
Forward barrier net	35
9 Intermediate barrier nets	200
Aft barrier net	20
Swing-tail separator net	20
10 Pallets at 140 lb	1,400
10 Pallet overthrow nets	180
Total removable equipment	2,070
TOTAL SYSTEM WEIGHT	2,620
GROSS PAYLOAD	66,000
SYSTEM WEIGHT 3.98% OF GROSS PAYLOAD	

CUBE LOSS IN MAIN COMPARTMENT

Volume lost due to depth of rubbing strips and pallets = 0.65/12 ft depth × 10 ft width × 76 ft length = 41 cu ft

TOTAL USABLE VOLUME IN MAIN COMPARTMENT = 4700 cu ft
PERCENTAGE VOLUME LOSS = 0.87%

Percentage volume loss with rollers and rigid pallets would be 5.4%

Let us first determine the annual utilization that a fleet of ten aircraft can be expected to produce first with hand loading methods and second with our mechanized system. For the purpose of this simplified comparison, we have assumed operation over a transcontinental route of 2,500 statute miles with an intermediate stop midway across the route. It also has been assumed that the full payload is unloaded and reloaded at each coast and half the payload is turned-around at the intermediate stop.

Figure 20 illustrates the round trip transcontinental flight plan for the two aircraft with the hand loaded airplane at the top and the mechanized aircraft at the

bottom. Following through the top schedule, 1 hour is allotted for a daily inspection at the start of the cycle. The empty aircraft is loaded in 3 hours, flies 1,250 miles to the intermediate stop in 3.62 hours, a 15 minute traffic delay is assumed at each stop, half the full cargo load is unloaded and reloaded in 2.75 hours, the aircraft flies the second 1,250 mile leg in 3.62 hours, another 15 minute traffic delay is introduced, the complete payload is unloaded and reloaded in 5 hours and the aircraft starts its return flight across the continent. After arrival at the other coast, the aircraft is unloaded in 2 hours and at this point a repair and maintenance allowance of 25% of the total flight hours, or 3.62 hours is introduced. This completes the cycle and it will be seen that the potential utilization of the hand loaded aircraft is 14.88 hours in 37.1 hours elapsed time.

The sequence of events follows the same assumptions for the mechanized aircraft except for the cargo loading and unloading times which are as follows:

(1) 36 minutes for loading the empty airplane,
(2) 45 minutes to turn-around half the payload at the intermediate stops,
(3) 1 hour to turn-around the full payload, and
(4) 24 minutes to unload when the aircraft has returned to its home base.

The potential utilization, in this case, is 14.88 flight hours in 24.1 hours elapsed time.

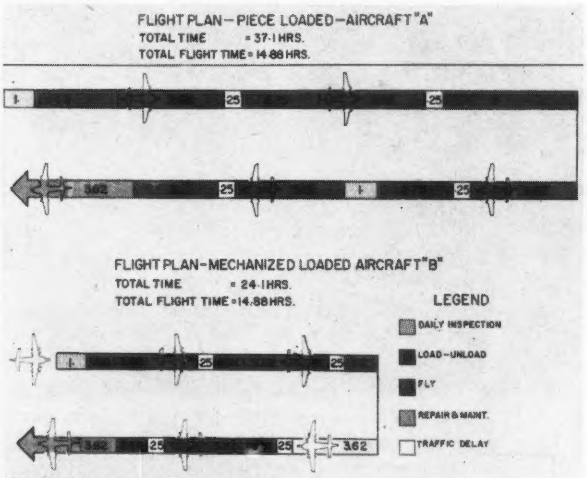


Figure 20
Round trip flight plan — piece loaded vs mechanized loaded aircraft

In determining actual utilization it has been assumed that a fleet of ten aircraft are required to maintain nine aircraft of the fleet at their maximum potential utilization. After applying this factor the probable utilization is found to be 3,120 hours per year for the piece loaded aircraft and 4,840 hours per year for the mechanized aircraft.

The Direct Operating Costs for the two aircraft calculated on the same basis, except for a 15% increase in spares depreciation for the mechanized aircraft, work out to be:

$485 per hour for the piece loaded aircraft and
$425 per hour for the mechanized aircraft.

Table 4
Depreciation, Mechanized Loading Equipment

Depreciation, Transfer Platforms	
Cost, 16 platforms at $40,000 each	$640,000
Annual depreciation	64,000
cost per a/c hour	1.35
Depreciation, Aircraft Fittings (M/C 65)	
Cost fixed fittings per a/c	16,000
Annual depreciation	1,600
cost per a/c hour	0.337
Depreciation, Pallets, Nets and Bins	
Cost 192 bins at $800 each	153,600
Cost 480 pallets at $350 each	168,000
Cost 480 overthrow nets at $150 each	72,000
Total	393,600
Annual depreciation	131,200
cost per a/c hour	2.70
Maintenance	
Total cost mechanized handling	1,193,600
Annual maintenance cost	119,360
cost per a/c hour	2.45
Hourly DO Cost	
Hourly cost excluding mech. loading effect	423
Cost/hr increase, Dep'n. & Maintenance mech. loading	6.8
Revised DO Cost/hr	429.8

We must now add to the Direct Operating Cost for the mechanized aircraft the cost of depreciation and maintenance for the loading platforms, pallets, nets and underfloor compartment bins.

Quantities have been determined on the basis of route analysis assuming operation from three airports on each coast and five intermediate stations. Liberal allowance has been made for spare pallets and bins. Transfer platforms and the fixed handling system in the aircraft have been depreciated to zero over ten years and pallets, nets and bins have been depreciated to zero over three years. Annual maintenance cost has been calculated to be 10% of the original equipment cost. The results are shown in Table 4.

Table 5
Operating Profit

Revenue derived from charge of 12¢/ton mile		
Aircraft "A" — Piece Loaded		
D O C per hour	$485.1	
Block speed	345 mph	
Payload	32.9 tons	
Annual utilization	3,120 hrs	
Total ton miles generated by 10 aircraft		354,500,000
Gross revenue		$42,500,000
D O C at $4.25/ton mile	$15,100,00	
I D C (100% D O C)	15,100,000	30,200,000
Net Profit/Annum at 100% Load Factor		$12,300,000
Aircraft "B" — Mechanized Loaded		
D O C per hour	$429.8	
Block speed	345 mph	
Payload	31.5 tons	
Annual utilization	4,840 hrs	
Total ton miles generated by 10 aircraft		526,000,000
Gross revenue		$63,100,000
D O C at $3.96/ton mile	$20,400,000	
I D C (100% D O C)	20,400,000	40,800,000
Net Profit/Annum at 100% Load Factor		$22,300,000

The significant conclusion from these results is that the added cost of procurement and maintenance of the mechanized equipment is a very small element of the total cost of fleet operation.

We can now proceed to the final step of comparing total operating cost and total revenue of the two aircraft fleets. In this comparison (Table 5) we have calculated indirect costs at 100% of direct, and average revenue has been determined on the basis of 12c/ton mile.

The results, as you can see, are quite conclusive. The potential profit from the fleet of mechanized aircraft is virtually double that which could be expected with piece loading.

It is recognized, of course, that these results have been based on a number of arbitrary assumptions which may or may not be typical or realistic for a particular operator on a particular route. We have found, however, that the conclusions are qualitatively correct over a wide range of conditions. Use of conventional piece loading methods can only be more profitable under circumstances where aircraft utilization is limited to a relatively low number of hours, well below its true potential.

REFERENCE

(1) Bickner, R. E. – *Cargo Density and Air Lift,* RAND CORP. REPORT No. RM 1853, 14TH JANUARY, 1957.

MID-SEASON MEETING

MARLBOROUGH HOTEL

WINNIPEG

27th and 28th February, 1961

27th February	Morning – 9.00 a.m. to 12.00 noon	Landing Engineering
	Afternoon – 2.00 p.m. to 5.00 p.m.	Runways – Prepared and Otherwise
	Evening – 7.00 p.m.	Dinner

Dinner Speaker and Guest of Honour: MR. G. W. G. MCCONACHIE

President, Canadian Pacific Air Lines, Limited

28th February	Morning – 9.00 a.m. to 12.00 noon	Air Traffic and Flight Control
	Afternoon – 2.00 p.m. to 5.00 p.m.	Training by Simulation

INTERPRETATION OF PROBE PRESSURES AND SOME ASSOCIATED PROBLEMS AT VERY LOW DENSITIES†

by Dr. G. N. Patterson,* F.C.A.I., and A. K. Sreekanth**

Institute of Aerophysics, University of Toronto

INTRODUCTION

ONE of the most common methods of calibrating wind tunnel flows and determining the flight speeds of aircraft and missiles is by means of pressure probes. Measurement and interpretation of pressures in low density wind tunnels which simulate high speed, high altitude conditions, and in missiles and satellites, require unique instrumentation and analysis due to the very low magnitude of the pressures involved. The purpose of this paper is to point out certain phenomena associated with the measurement of low pressures, to discuss the interpretation of probe pressures and to describe briefly the properties and uses of free molecule flow pressure probes that have been developed recently. A short review of various pressure measuring devices used in low density work is also included.

The basic parameter that indicates the degree of rarefaction of a gas is the Knudsen number, Kn, defined as $Kn = \lambda/L$ where λ is the molecular mean free path (i.e. average distance traversed by molecules between collisions) and L is the characteristic body dimension. The Knudsen number can also be expressed in terms of the Mach number, M, and the Reynolds number, Re (the two basic parameters used in continuum mechanics) by the relation

$$Kn = 1.26 \sqrt{\gamma}\, M/Re \qquad (\gamma = \text{ratio of specific heats})$$

where both Kn and Re are based on the same characteristic length.

Gas dynamics can be divided roughly into the following regions according to the degree of rarefaction measured by the Knudsen number:

Continuum flow	$Kn < 0.01$
Slip flow	$0.01 < Kn < 0.1$
Transition flow	$0.1 < Kn < 5$
Free molecule flow	$Kn > 5$

The analyses of transition and free molecule flows are based on the kinetic theory of gases, whereas the continuum and slip flows are characterized by the Navier-Stokes equations of motion, with proper boundary conditions, derived fundamentally on the basis of continuum mechanics.

In free molecule flow ($Kn > 5$), collisions between molecules themselves can be neglected compared with the collisions with the body. In this type of flow, motions of incident and reflected streams of molecules may be treated separately. This postulation allows the molecules to have a Maxwellian (equilibrium) velocity distribution, and the flow phenomena are governed only by the molecule-surface interaction.

In the transition regime in which the mean free path is of the same order of magnitude as the characteristic body dimension, both the intermolecular collisions and the molecule-surface interactions must be considered and the flow phenomena become complicated.

Another important flow parameter that appears is the analyses of highly rarefied gas flows in the speed ratio, S, defined as the ratio of mass (or macroscopic) velocity to the most probable molecular velocity[1]. This is analogous to the Mach number in continuum flows and since both the most probable molecular velocity and the speed of sound are functions of the temperature, they can be related by the following expression,

$$S = \sqrt{\gamma/2}\, M.$$

MEASUREMENT OF LOW PRESSURES

Choice of an instrument

Measurements of the pressure at a point on a body or probe in a low density flow require the use of pressure sensitive elements, known as pressure gauges or vacuum gauges. Many types of vacuum gauges have been developed and are commercially available. The choice of a suitable gauge depends not only on the magnitude of the pressures to be measured but also on its physical size and accuracy, and, when used in flight vehicles, its ability to record and transmit the data remotely. For example to measure a certain pressure, one could use a McLeod gauge in the laboratory but its use in a rocket is not practicable and one has to resort to an electrical recording gauge, such as an

†Paper received 11th March, 1960.
*Director
**Research Fellow

TABLE 1

Gauge	Useful Pressure Range (microns Hg)	
	Upper limit	Lower limit
Bourdon	760×10^3	100
McLeod	10^3	10^{-2}
Hot Wire	10^2	10^{-2}
Quartz membrane	10^2	10^{-4}
Knudsen	10	10^{-5}
Ion	10^2	10^{-6}

ionization gauge. Table 1 gives the approximate ranges of commonly used pressure measuring instruments.

We will consider briefly the principles of operation of some of the above gauges. For complete details of all the gauges see Reference 2.

McLeod gauge

The McLeod gauge is a primary standard for measuring low pressures. The gauge requires external actuation and therefore measures the pressure intermittently. The principle of operation is: a certain known volume of the gas at the pressure to be measured is trapped and compressed to a measured final volume and pressure in such a way that Boyle's gas law can be used to determine the unknown pressure. The range and sensitivity of the gauge can be varied by varying the gauge geometry. The McLeod gauge is used only in stationary facilities such as wind tunnels etc and for calibrating other secondary gauges (e.g. thermal conductivity gauges).

Thermal conductivity gauge

The thermal conductivity of gases at low pressures is a function of the pressure, and this phenomenon is utilized in the operation of thermal conductivity gauges. In essence, a thermal conductivity gauge consists of a heated filament within an enclosure which is exposed to the gas pressure to be measured.

Energy is dissipated from a heated filament in the following ways: (1) by radiation, (2) by conduction through the surrounding gas, and (3) by end conduction (conduction through the filament supports). At normal pressures, the heat transfer by conduction through the gas is given by

$$E_c \propto \lambda \left(\frac{dT}{dx}\right)$$

where λ = thermal conductivity
dT/dx = temperature gradient.

At low pressures, when the mean free path of the gas molecules is comparable with or greater than the characteristic dimension of the gauge enclosure, the heat loss by conduction is

$$E_c = \frac{4}{3} \cdot \frac{a}{2-a} \Lambda_m p \sqrt{\frac{273}{T_o}} (T_i - T_o) \quad \text{watts/cm}^2$$

where Λ_m = molecular heat conductivity in watts/cm^2 at zero degrees C

a = accommodation coefficient defined by $\dfrac{T_r - T_o}{T_i - T_o}$

p = pressure in microns Hg

T_i = temperature of the heated element

T_o = temperature of the cold surface or the gas

T_r = temperature of the molecules reflected from the filament.

The above expression shows that if one neglects the end conduction and radiation losses, the heat loss from a heated filament is a direct function of pressure for a given T_i and T_o. There is no theoretical lower limit to the operation of a thermal conductivity gauge except for the fact that heat transfer from the filament becomes extremely small at pressures lower than 10^{-5} mm Hg. Because of the very small physical size of the gauge and its capability of remote operation and recording, thermal conductivity gauges are most widely used. Heat loss from the filament is determined either by measuring the temperature by a thermocouple (thermocouple gauges) or by measuring the change in resistance of the wire (pirani gauges). In recent years the development of semi-conductors and thermistors possessing a very high negative temperature coefficient have replaced the filament.

The main disadvantages of the thermal conductivity gauges are: (1) the gauge requires periodic calibration against a primary gauge such as the McLeod gauge, (2) calibration changes as the emissivity or the accommodation coefficient of the filament varies, and (3) calibration is valid when the gauge is exposed to only one gas during calibration and operation. Hot wire gauges can be used in flight vehicles, provided the composition of the air is known at the place where the pressure is being recorded by the gauge.

Knudsen gauge

This gauge is based on the principle of radiometric force, i.e. at low pressures a mechanical force is exerted between two surfaces if they are maintained at different temperatures. This is due to the fact that molecules rebounding from the hot surface possess a higher kinetic energy than those that rebound from the cold surface. For a particular temperature condition, the mechanical force produced is a direct function of the pressure. The Knudsen gauge is an absolute instrument and measures pressures mainly in the range 10^{-3} mm to 10^{-8} mm. The action of the gauge is independent of the molecular weight of the gas. Due to extreme sensitivity to vibrations and the delicateness of the suspension, the gauge is not suitable for measuring pressures in flight vehicles.

Ionization gauges

Electrons acquire a high kinetic energy in passing through a region of potential difference. If the energy of the electrons is high and above a certain critical value, collisions between electrons and molecules occur resulting in the formation of positive ions. For a constant value of the potential difference, the forma-

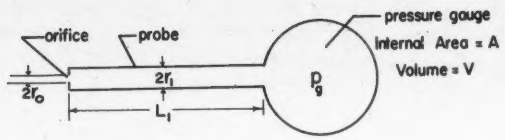


Figure 1

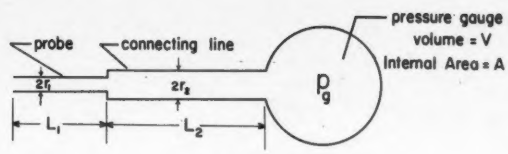


Figure 2

tion of ions is a direct function of pressure for a given temperature. Hence the determination of the rate of production of positive ions for a given emission current is a measure of the pressure. Instruments based on this principle are known as ionization gauges. Ionization gauges can be divided into three types depending upon the manner in which the electrons are produced. They are: (1) cold cathode ionization gauge (Philips Gauge), (2) hot wire or thermionic ionization gauge, and (3) alphatron gauge, which uses an external radioactive source to produce electrons.

At present the ionization gauges are most widely used for the measurement of pressures in flight at high altitudes.

RELATED PROBLEMS IN PRESSURE MEASURING SYSTEMS

Time constant and outgassing

Having chosen a suitable instrument to measure the pressure, one is left with the problem of designing an optimum pressure measuring system. Time response of pressure measuring systems at low pressures has been subject to various theoretical and experimental investigations. Time constant of the system is defined as the time required for the system to come within $1/e$ of the total change. Methods for determining the time lag of pressure measuring systems in continuum flows are given in References 3 and 4. At low pressures, the pressure measuring systems are subject to outgassing. Outgassing is defined as the release of adsorbed or occluded gas from a surface placed under vacuum. When pressure probes or orifices are used in low density flows, the gas evolving from the gauge volume and the connecting tube will be flowing out of the probe of the orifice and gives rise to a pressure drop across the measuring system. Schaaf and Cyr[5] have derived expressions for determining the outgassing pressure drop and time response in free molecule flow. For a system consisting of a tube with an orifice at the end connected directly to the measuring gauge (see Figure 1) the expressions are

$$p_{gauge} - p = C'Q' \left[\frac{8A}{3r_o^2} + \frac{AL_1}{r_1^3} + \frac{16\pi r_1 L_1}{3r_o^2} + \frac{\pi L_1^2}{r_1^2} \right]$$

$$t_L = C' \left[\frac{VL_1}{r_1^3} + \frac{8V}{3r_o^2} + \frac{8\pi r_1^2 L_1}{3r_o^2} + \frac{\pi L_1^2}{3r_1^2} \right]$$

where $C' = 0.75\sqrt{2\pi RT} = 2.6 \times 10^{-5}$ sec/inch for air

p_g = gauge pressure, microns Hg

p = pressure external to orifice microns

Q' = outgassing rate micron inch/sec

t_L = time constant

For probe and gauge geometries encountered in practice, Harris[6] has shown that the outgassing pressure drop and the time constant are related by

$$p_{gauge} - p = \frac{Q'A}{V} t_L$$

Expressions have also been derived for a system in which the probe is connected to the gauge volume through a connecting tube of radius r_2 and length L_2 (Figure 2).

$$p_{gauge} - p = Q'C' \left\{ \frac{AL_2}{r_2^3} + \frac{\pi L_2^2}{r_2^2} + \left(\frac{L_1}{r_1^3} + \frac{8}{3r_o^2} \right) \left(A + 2\pi r_1 L_1 + 2\pi r_2 L_2 \right) - \frac{\pi L_1^2}{r_1^2} \right\}$$

It is seen from the above expression that for given dimensions of the probe, the gauge and the length of the connecting line (L_2) there is an optimum radius (r_2) of the connecting tube for a minimum outgassing pressure drop. Curves are presented in Reference 6 giving the optimum tube radius and the outgassing pressure drop in terms of the system geometry and outgassing rate. There will always be some outgassing pressure drop across the line and this might be quite appreciable in some cases. A correction for outgassing error has to be applied when measuring pressure under such conditions. Detail experimental investigation of the effect of outgassing on the pressure readings have been done by Enkenhus[7]. According to him two pressure readings are necessary, one with the gauge exposed to the pressure to be measured and the other with the gauge exposed to a very high vacuum. The difference between these two readings give the true pressure.

Thermal transpiration

A pressure drop occurs across a tube at low pressures if the ends are at different temperatures. This phenomenon is known as thermal transpiration and a correction has to be applied for this when measuring the pressures. Thermal transpiration occurs across an orifice also if the temperatures on either side of the orifice are different. In free molecule flow the magnitude of this thermal transpiration effect is

$$\frac{p_2}{p_1} = \sqrt{\frac{T_2}{T_1}}$$

where the subscripts 1 and 2 refer to the conditions on either end of the tube or on either side of the orifice.

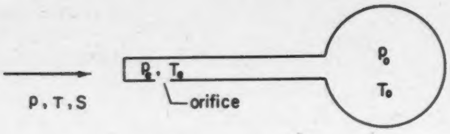


Figure 3

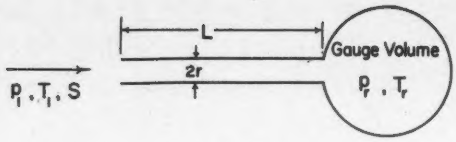


Figure 4

In a typical orifice pressure probe system, as shown in Figure 3, the pressures and the temperatures are related by

$$\frac{p_o}{p_e} = \sqrt{\frac{T_o}{T_e}}$$

$$\frac{p_e}{p} = \sqrt{\frac{T_e}{T}} \,.\, \mathrm{f}(\text{Speed ratio, } S)$$

The above expression can be combined to give

$$\frac{p_o}{p} = \sqrt{\frac{T_o}{T}} \,.\, \mathrm{f}(\text{Speed ratio})$$

The determination or the knowledge of the temperatures of the gauge volume and the free stream is one of the prerequisites to interpret the measured pressure. We will see later how the dependence of the pressure on the temperature is eliminated in the case of an orifice probe used to determine the speed ratio in free molecule flows. Expressions for the thermal transpiration in slip flows can be found in Reference 8 (pages 330 to 332).

PRESSURE PROBES AND INTERPRETATION OF MEASURED PROBE PRESSURES

Pressure probes are commonly used to determine the Mach number. Under ordinary conditions, the Mach number may be calculated from the ratio of impact (pitot) to static pressure using the Rayleigh formula for supersonic flow and the isentropic relation in the subsonic flow. At high altitudes the rarefaction of the air makes the measured pressure depart radically from the theoretical values. This is due to the effect of very low Reynolds number (viscous effects) and the onset of slip flow. Pressure interpretation of the conventional impact probe in continuum, slip and free molecule flows and the properties and uses of the newly developed free molecule flow probes, known as the orifice probes, are discussed in some detail below.

Impact probe

The impact probe consists in essence of an open ended tube with axis aligned to the flow direction, one end facing the oncoming flow and the other connected to a pressure gauge. The measured pressure known as the 'pitot' pressure can be related to the Mach number and free stream static pressure in continuum flow and to the speed ratio, static temperature and pressure in free molecular flow.

Continuum and slip flow

If the Reynolds number of the flow based on the probe diameter is greater than 200, viscous effects on the probe readings are negligible, and the measured pressure is related to the Mach number and static pressure by the following relations,

$$\frac{p_{\text{pitot}}}{p_{\text{static}}} = \left(\frac{\gamma+1}{2}M^2\right)^{\gamma/\gamma-1}\left[\frac{2\gamma}{\gamma+1}M^2 - \frac{\gamma-1}{\gamma+1}\right]^{-1/\gamma-1} \text{for } M \geqslant 1$$

$$\frac{p_{\text{pitot}}}{p_{\text{static}}} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{\gamma/\gamma-1} \text{for } M \leqslant 1$$

When the Reynolds number is less than about 200, the measured pressure is a function of Mach number, probe shape and Reynolds number. Extensive theoretical and experimental works on the viscous effects on impact probes in continuum and slip flows have been done[9, 10]. According to these investigations the viscous corrections to the measured pressure can be expressed in the following form:

$$\text{Supersonic flow} \quad \frac{(p_{\text{pitot}})_{\text{meas}}}{(p_{\text{pitot}})_{\text{ideal}}} = \mathrm{f}(M, Re, \text{probe shape})$$

$$\text{Subsonic flow} \quad C_\mu = \frac{(p_{\text{pitot}})_{\text{meas}} - (p_{\text{pitot}})_{\text{ideal}}}{\tfrac{1}{2}\rho S V^2} = \mathrm{f}(M, Re, \text{probe shape})$$

Viscous correction graphs for impact probes of various shapes are presented in References 10 and 11. In applying these viscous corrections, an iterative procedure has to be adopted as the true Mach number and Reynolds number are not known to start with.

Free molecule flow

If the mean free path is much greater than the diameter of the impact probe, the flow inside the tube will be a free molecule flow. Patterson and Harris[12] have derived a formula based on kinetic theory of gases, relating the measured pressure to the free stream conditions. The assumptions made are that the molecules are reflected from the tube walls diffusely and the free stream has a Maxwellian velocity distribution for random motion superimposed on the mass velocity. The concepts involved in the analysis and the final form of the result is presented in Figure 4. The molecules from the free stream enter the gauge volume in two ways:

(1) by travelling direct to the gauge volume from the free stream without striking the walls of the tube, and

(2) of those molecules that hit the inner wall of the tube, some will find their way in to the gauge volume by one or more diffuse reflections with the wall.

Let $W(S, 2r/L)$ be the probability that a molecule, which enters one end of the tube, will reach the other end after one or more collisions with the inside surface of the tube. The probability of a molecule escaping

from the gauge volume to the free stream is obtained by setting $S = 0$ in the expression for W and will be denoted by $W(0, 2r/L)$. Reference 12 gives the details of the methods involved for determining the value of W. Under steady conditions the number of molecules entering the gauge volume per unit time must be equal to the number of molecules leaving the gauge volume in unit time. Then it can be shown that

$$\frac{p_r}{p_1}\sqrt{\frac{T_1}{T_r}} = \frac{W(S, D)}{W(O, D)}; \qquad D = \frac{2r}{L}$$

where

$$W(S, D) = \chi(S) - e^{-S^2}\{\alpha\psi(D) + (1 - 2\alpha)\zeta(D)\} - \left(\frac{4S}{\sqrt{\pi}}\right)\{\alpha\eta(S, D) + (1 - 2\alpha)\,\omega(S, D)\}$$

$$\psi(D) = \left(\frac{2}{D^2}\right)(\sqrt{1+D^2}-1); \quad \zeta(D) = \left(\frac{2}{3D^2}\right)[(1+D^2)^{3/2} - D^3 - 1]$$

$$\chi(S) = e^{-S^2} + S\sqrt{\pi}\,(1 + \text{erf}\, S)$$

$$\eta(S, D) = \frac{1}{D}\int_0^1 dY \int_0^{\tan^{-1}(D+\sqrt{1-Y^2})} (1 + \text{erf}\, S\cos\phi)\cos\phi\, e^{-S^2 \sin^2\phi}\, d\phi$$

$$\omega(S, D) = \int_0^1 \eta(S, D/x)\, dx$$

α = function of D only (Reference 13).

It is of interest to note that the above formula contains a probe geometry parameter D, in contrast to the Rayleigh formula in continuum flows which is independent of the probe shape. Also the ratio of free stream static to gauge volume temperatures needs to be known to interpret the measured pressure. Comparison between experiment and theory of long tube impact pressure probe is shown in Figure 5.

Static probe

Cone static probes are generally used to measure the static pressure in supersonic flows. Taylor-McColl's theory of flow over cones is applied to interpret the measured pressure. The measured pressure begins

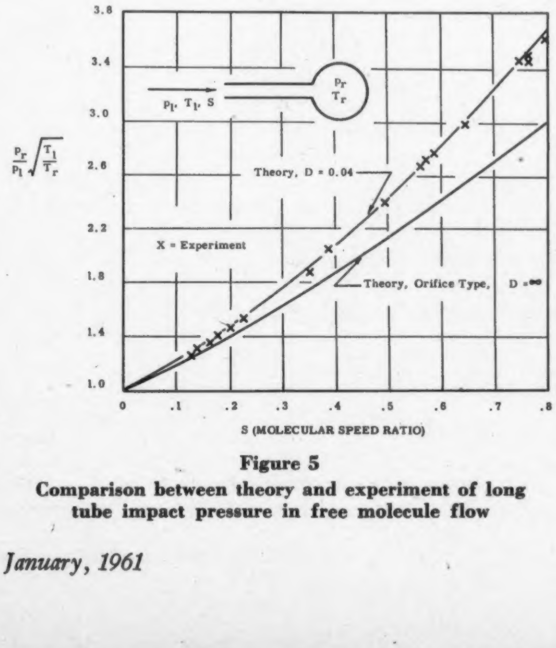


Figure 5
Comparison between theory and experiment of long tube impact pressure in free molecule flow

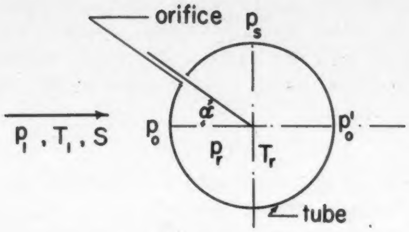


Figure 6

to deviate from the above theory at a Reynolds number of approximately 10^4. At low Reynolds numbers the measured pressure can be related to the true or ideal pressure by the following relation[14]

$$C_p = \frac{p_{\text{meas.}} - p_{\text{ideal}}}{p_{\text{ideal}}} = \frac{f(M, \theta)}{\sqrt{Re_L}}$$

where p = Pressure on the surface of the cone,

θ = Semivertex angle of the cone,

Re_L = Reynolds number based on the distance from cone tip to the orifice

An experimentally determined viscous correction chart for cone static probe readings at low Reynolds numbers is available only for the flow at a Mach number of 4 (Reference 14).

A circular plate with a pressure tap at its centre, set parallel to the flow was successfully used by Enkenhus[10] to measure the static pressure in low density subsonic flows. In this case the diameter of the plate was comparable with the mean free path.

An orifice probe, described in the next section, can be used to measure the free stream static pressure in free molecule flows if the orifice is set at 90° to the direction of mass velocity.

Orifice probes in free molecule flow

An analysis based on the kinetic theory of gases, derived by Patterson[15], revealed that in free molecule flow simple expressions can be obtained relating the measured pressure to the free stream conditions when the length of the impact probe is zero, i.e. an orifice. Probes of such a kind are known as orifice probes.

Consider a pressure probe in the form of an orifice in the side of a tube whose diameter is less than the mean free path (Figure 6). Let p_1, T_1, S be the pressure, temperature and the speed ratio of the free stream and p_r, T_r the pressure and temperature inside the probe (Figure 6).

By equating the number of molecules entering the orifice from the free stream in unit time to the number of molecules escaping through the orifice in unit time from inside the tube, it is possible to show the following relation for a Maxwellian gas

$$\frac{p_r}{p_1}\sqrt{\frac{T_1}{T_r}} = e^{-S^2\cos^2\alpha} + \sqrt{\pi}\, S\cos\alpha\,(1 + \text{erf.}S.\cos\alpha)$$

$$\text{where erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}\, dt$$

Experiment has revealed that the temperature inside the probe, T_r, is practically constant for various values of α. If we evaluate the above expression for $\alpha = 0$; $\alpha = \pi/2$ and $\alpha = \pi$ we obtain the result

$$S = \frac{p_o - p_o'}{2\sqrt{\pi}\, p_o}$$

Therefore it is possible for a free molecule flow orifice probe to give a direct measurement of the speed ratio in terms of pressures only. This has been experimentally verified in the low density wind tunnel[10].

It is interesting to note that neither the size of the orifice nor its shape matters so long as it is plane and has a diameter much smaller than the mean free path.

Patterson has extended his orifice probe theory[15] for the case of a non-isentropic flow, thereby increasing the usefulness of the probe by making it possible to study the boundary layers and shock waves in the flow.

Free molecule flow orifice probes have been successfully constructed by cementing thin tin foil with an orifice pierced in it over an opening on the side of a cylindrical stem. Experiments performed in the UTIA low density wind tunnel on orifice probes have confirmed the theoretical analyses.

CONCLUSION

Except for very limited theoretical work, the knowledge of the flow problems in slip and transition flow regions is governed by empirical or semi-empirical relations. However in free molecule flow the theoretical analyses are much simpler, thereby resulting in an accurate interpretation of the experimental data. The development of the orifice probes have made possible some fundamental experimental work in very low density gas flows. These probes have been used so far to determine the speed ratio and to study the flow over a flat plate in a low density wind tunnel. Its use, for the first time, in a rocket has been contemplated, and work toward this end is already in progress at the Institute of Aerophysics, University of Toronto, under the direction of Dr. G. N. Patterson.

REFERENCES

(1) Patterson, G. N. — *Molecular Flow of Gases*, J. Wiley & Sons, 1956.

(2) Dushman, S. — *Scientific Foundations of Vacuum Technique*, J. Wiley & Sons, 1949.

(3) Kendall, J. M. — *Time Lags Due to Compressible-Poiseuille Resistance in Pressure Measuring Systems*, NOL Memo No. 10677, May, 1950.

(4) Sinclair, A. R., and Robins, A. W. — *A Method for the Determination of the Time Lag in Pressure Measuring Systems Incorporating Capillaries*, NACA TN 2793, September, 1952.

(5) Schaaf, S. A., and Cyr, R. R. — *Time Constants for Vacuum Gage Systems*, Jour. of Appl. Phy. Vol. 20, No. 9, 1949.

(6) Harris, E. L. — *Investigation of the Time Response and Outgassing Effects of Pressure Probes in Free Molecule Flow*, UTIA TN No. 6, 1955.

(7) Enkenhus, K. R. — *The Design, Instrumentation and Operation of the UTIA Low Density Wind Tunnel*, UTIA Rep. No. 44, 1957.

(8) Kennard, E. H. — *Kinetic Theory of Gases*, McGraw Hill Book Co., 1938.

(9) Ladenburg, R. W., et al. — *Physical Measurements in Gas Dynamics and Combustion*, Vol. IX, High Speed Aerodynamics and Jet Propulsion. Princeton University Press, 1954.

(10) Enkenhus, K. R. — *Pressure Probes at Very Low Density*, UTIA Rep. No. 43, 1957.

(11) Sherman, F. S. — *New Experiments on Impact Pressure Interpretation in Supersonic and Subsonic Air Streams*, NACA TN 2995, 1953.

(12) Harris, E. L., and Patterson, G. N. — *Properties of Impact Pressure Probes in Free Molecule Flow*, UTIA Rep. No. 52, 1958.

(13) Clausing, P. — *Uber die Stromung Sehr Verdunnter Gase durch Rohren von Belieber Lange*, Ann. der Physik, Vol. 12, 1932.

(14) Talbot, L. M. — *Viscosity Corrections to Cone Probes in Rarefied Supersonic Flow at a Nominal Mach No. of 4*, NACA TN 3219.

(15) Patterson, G. N. — *Theory of Free Molecule Orifice — Type Pressure Probes in Isentropic and Non-Isentropic Flows*, UTIA Rep. No. 41 (Revised), 1956.

(16) Harris, E. L. — *Investigation of Free Molecule and Transition Flows near the Leading Edge of a Flat Plate*, UTIA Rep. No. 53, 1958.

RECENT RESEARCH IN ARCTIC METEOROLOGY†

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SUMMARY

A brief discussion of the history of arctic meteorology is followed by a more detailed description of research in Canada and other northern countries in the field of surface and high-level atmospheric phenomena. An attempt is made to show the importance of such research in meteorology to northern transportation, both surface and air.

INTRODUCTION

I LOOKED up "Aeronautical Research" in *Collier's Encyclopedia* and found that it is defined as "the study of natural phenomena that occur in flight or that relate to flight. The research usually extends to a study of means for controlling a sequence of physical events for the purpose of improving aircraft performance and operation."

It seems that a great many of the natural phenomena that occur in flight are meteorological, and, indeed, the history of research in the two fields has something in common. Meteorology of the ancients was a non-instrumental science, the weather was studied in relation to the duration and direction of the wind, and in the first century B.C. Andronicus of Cyrrhus built, in Athens, his "Horologium" or "Tower of the Winds". Aristotle, who died in 322 B.C., was the ancient weather authority, and after him little of importance happened for almost two thousand years.

Heron of Alexandria, author of "Pneumatica" and inventor of the Aeolipile, belongs to aviation history, although he lived as long ago as the second century B.C. His invention was in reality the first reaction turbine and was based on the same principle as the propulsive power of a jet engine. Also in this field did it take about two thousand years for scientists, engineers and inventors to approach complete understanding of their environment. It was aviation which gave meteorology the hardest push forward; knowledge of the atmosphere had grown slowly until the aircraft made it imperative to have information in detail about such things as upper winds, clouds, icing and turbulence, and meteorological conditions on the ground as well, for the aeroplane soon reached and was used in the far places.

The Arctic was in a meteorological sense, until quite recently, such a far place. Only since the Second World War have we been obtaining regular aerological data from the Arctic. Before that time one had learned many facts about the surface climatology and about the lowest layers of the atmosphere from adventurous expeditions, beginning with the results of the first Polar Year (1882-83) and continuing through a series of arctic ship expeditions. Such were the Norwegian "Fram" Expeditions under Nansen (1893-96) and Otto Sverdrup (1898-1902), the latter located in and around the northern part of the (now) Canadian Arctic Archipelago — where names like Axel Heiberg Island, Amund, and Ellef Ringnes Islands testify to Norwegian brewers' interest in supporting arctic exploration in the days gone by.

Some of the most important information ever collected about Arctic Ocean currents, ice and near-surface meteorology came out of the famous Norwegian "Maud" Expedition, 1918-25. Then came the second Polar Year (1932-33), when sixteen nations participated, and the surface station network was extended to cover unknown areas both on the mainland and in the Arctic islands. The icecap of Greenland was studied by two expeditions in 1930-31, one German and one British, the latter named "The British Arctic Air Route Expedition", which signifies the importance attached to new knowledge of meteorology from the areas that only thirty years ago were thought to house the necessary intermediate stopping places on long-distance air routes.

In 1937-38 the Russians put the first scientific party onto the polar sea ice itself, when they landed an aircraft at the North Pole and established a camp which drifted on an ice floe for eight months until picked up off the east coast of Greenland.

RECENT RESEARCH

After the Second World War, meteorological research in the Arctic increased tremendously. During the years 1947-52 the Joint Arctic Weather Stations were established in the North American Arctic, and now instruments were available for the obtaining of regular aerological data from the high latitudes. Not only were radiosonde ascents done from the surface, but "dropsondes" were released from high-flying aircraft over the Arctic Ocean as well, adding to the observing network where no surface stations existed.

The pioneering work of the Russians in landing scientific observers on the pack ice was gradually extended; a series of drifting stations have been manned by them, and since 1952 ice island T-3 has been occupied almost

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continuously by American scientists and from time to time by other nationals as well.

Then came the International Geophysical Year, 1957-58. A vast increase in geophysical observations from the Arctic, both land and ocean, was the result of this immense effort, and some of the extra work has continued after the IGY, and seems to have become permanent. I do not think that we can afford to decrease our observational programme in the Arctic, nor the continued research into arctic geophysics, with the data now available. Both from the permanent weather stations with their regular three-hourly surface observations and twice-daily aerological soundings, and from the IGY expeditions and later special research groups, we have a fair knowledge of climatological conditions, both from the surface and upper air. Most of the stations were, of course, established to meet the need of polar aerology, rather than surface climatology, and yet all levels are of importance in arctic air transportation. As far and as fast as the aircraft may fly, the problems of terminal forecasting and surface climatology are, at least, as important as before. The present location and average distance between the arctic stations (approximately 300 miles) are satisfactory on aerological grounds but not always desirable as far as a study of surface conditions is concerned.

Still, we do have, and we are continuously receiving, vast amounts of observational material. What use is being made of these data?

First of all, daily weather maps are now prepared for the polar region. The Canadian Meteorological Service, at its Edmonton forecast office, draws two surface and two 500 mb (ca. 18,000 ft) circumpolar maps daily. McGill University's Arctic Meteorology Research Group, with the assistance of the Meteorological Service's Central Analysis Office at Dorval Airport, draws daily synoptic charts at 200 mb (38,000 ft), 100 mb (53,000 ft) and 30 mb (78,000 ft). The 200 mb maps are circumpolar, data being received also from Russian sources on a current basis. The 100 mb and 30 mb maps are analyzed over a smaller area, every fifth map being subsequently extended to a circumpolar area by the use of climatological data. Vertical cross sections are also constructed, running from the Panama Canal Zone to Alert, along the 80°W meridian and extending to 100,000 ft when data permit. We are thus able to obtain a detailed three-dimensional picture of the stratospheric circulation, probably more detailed, in fact, than that obtained at any other centre, except perhaps for the US Weather Bureau group at Suitland, Md., under S. Teweles, and that maintained by Dr. R. Scherhag at the Free University, West Berlin.

Several services do, of course, work on problems of direct operational importance and in operational forecasting etc. Such services are the meteorological organizations of the different armed forces and the airlines. Their work often consists of preparing forecast studies for particular areas, and regional climatologies. Often, however, these operational problems have been those of the surface and near-surface levels, and the study of the aerological material from the Arctic is quite recent. Important research has been done during the past few years into such basic problems as the nature of the general circulation in the Arctic region, the polar stratospheric temperature and wind fields, reversal with season of temperature and wind, sudden changes of temperature in the Arctic stratosphere, the polar night jetstream, synoptic activity in the Arctic, "cold lows", ozone contents and changes in the stratosphere etc. The list of References (1 to 20) gives the titles of some of these contributions.

Also arctic surface research has been accelerated recently. In addition to the regular installations in the north, there have been in the years since the Second World War a number of expeditions to the Arctic investigating surface conditions in particular areas. Some of these expeditions have been located wholly or partially on ice surfaces. Such were the Baffin Island Expeditions of the Arctic Institute of North America in 1950 and 1953. From these we learned something about the processes which take place at the surface, and govern the budget of the ice and snow masses. Meteorological conditions, both current and past, are reflected in the state of the glaciers and icecaps. Glacial-meteorology has been studied on the Greenland Icecap as well, by the French Greenland Expedition, 1949-52, and the British North Greenland Expedition, 1952-54. The Greenland Ice cap is giving up its secrets too, to continuous research undertaken by the American Snow, Ice and Permafrost Research Establishment.

In Alaska the US Air Force's Cambridge Research Center is engaged in regional studies, including micrometeorology, of the arctic side of the Brooks Range. The Canadian Defence Research Board has investigated the ice shelf of northern Ellesmere Island, the probable source region of the largest of the floating ice islands. One of these, T-3, has been used as a most satisfactory platform from which to study the meteorology, oceanography and bottom topography of the polar ocean. The drifting pack ice stations which have been occupied for varying periods of time, mainly by the Russians, are not quite so satisfactory as they are subject to the gigantic pressures of the polar pack. How many of these so-called "North Pole" stations the Russians have been forced to abandon in a hurry, we do not know, but they have been running eight or nine of them during the past two decades. Two similar American pack ice stations have been manned since 1957, both of them had to be abandoned due to ice pressure. As Thor Heyerdahl and his companions found when they drifted across the Pacific on the raft "Kon-Tiki", there is no better way of studying the sea than by living right on its surface. So also have the pack ice stations shown the value of observations taken a few feet above the polar water.

The ice itself has also been subjected to study, test and experiment. McGill University's physics professor, Dr. E. Pounder, has for several years been engaged in such work, which of course has some tradition at McGill, as Professor Barnes in his day was a leading researcher in ice physics, although he was more interested in river ice.

Also inland in the arctic islands the problems are gradually becoming crystallized. During the IGY, the Defence Research Board ran a research station at Lake Hazen in Ellesmere Island (81°49'N), from the spring of 1957 until September 1958. University personnel and

DRB researchers shared the task of geophysical investigations in the lake and mountain region of that northern part of the Canadian Archipelago, which from the air had seemed to be a specially favourable location as far as a lack of cloud cover was concerned. The surface and mass energy budgets of the nearby glaciers were also examined. The Canadian Meteorological Service, of course, extended considerably its northern observational programme during the IGY, with special emphasis on the heat radiation balance. Much of this work is still continuing.

IMPORTANCE OF RESEARCH TO NORTHERN TRANSPORTATION

Low temperatures alone seem to have little adverse effect on man and machinery. However, low temperatures coupled with relatively high humidities or wet ground surfaces, or high wind speeds, subject both man and equipment to the most trying and even dangerous climatic conditions. The term "windchill" is used for the loss of heat (kgcal/m^2/hr) from a surface over which flows turbulent air. The windchill is calculated from a formula which contains wind speed and temperature; therefore, it is possible to draw climatic maps of this parameter, and to calculate it for any one station for any period for which these elements are observed. Planning of surface operations should take this parameter into consideration, as well as other environmental factors of a climatological nature. Another example of such factors is "cold-wet" conditions, certain combinations of temperature and precipitation, fog and wet ground. At McGill University a research project is under way at the present time, consisting of analyzing and presenting climatic frequency data for Alaska, the Canadian Arctic, Greenland and Eurasia, for 326 observing stations, showing temperature frequencies, cold-wet conditions and frequencies of different wind speeds. The analyzed data are being published in a series of reports and atlases, which should be of interest to engineering, research and development personnel who have a continuing need for information on climatic factors affecting the operation of equipment in the North. Reference 21 is one of these tabulations.

In general it is true to say that "climatic conditions" are reflected in the distribution and state of snow and land ice, sea ice and permafrost. These have all received increasing attention during the past 15 years. In 1946 the sea ice conditions in the Canadian Arctic and particularly in the Arctic Archipelago were to all intents and purposes unknown. That year a US Navy Task Force surveyed ice conditions in Baffin Bay and in the Arctic Islands, in connection with the establishment of the Joint Weather Stations. In 1949 the RCAF took over this programme, and in 1956 the Joint Committee on Oceanography had set up a working group for ice research and at the same time the Canadian Meteorological Service set up an ice reporting and forecasting group for the Eastern Arctic. This work has now been extended to cover the whole Canadian Arctic. Ice information about any particular area can now be obtained from several offices, both in Canada and in the USA. Such are the Meteorological Service in Toronto, the Geographical Branch of the Department of Mines and Technical Surveys in Ottawa, the "Working Group on Ice in Navigable Waters" at the DRB in Ottawa and the USN Hydrographic Office in Washington, D.C. Some good references exist[22, 23], which can be of help in outlining the areas impossible or only barely passable for ships in late summer. Work is progressing on an ice probability atlas of the Canadian Arctic, which will show probability of encountering ice, together with its navigability, at 325 spots in the Canadian Arctic north of the mainland.

Both to ships and heavy aircraft some climatic facts are of importance in planning operations. Firstly, ice conditions can vary widely from year to year; secondly, extreme temperatures are far more severe in their effects on men and machinery in the dark period than comparable temperatures in lower latitudes where there is some insolation; thirdly, without radio aids VFR flying is restricted severely after the air temperatures rise above 28°-32°F, and is of course difficult in twilight and darkness. The only good VFR flying weather is between early March and mid-June. Thus, small aircraft should be operated, if possible, mainly during this period. More must be found out about the frequencies of occurrence of blowing snow and whiteout conditions in many parts of the Arctic.

Finally, recent research has shown that many parts of the Arctic have extremely light precipitation, and lack of water may have serious consequences at poorly chosen base or camp locations.

Permafrost conditions will seriously affect mobility of vehicles during the thaw period, and if beaches or camp sites are chosen where the soils are cohesive or the granular material can break down into cohesive materials, complete immobility may be the result. Detailed mapping and study of the permafrost is an absolute requirement for a complete understanding of the arctic environment, not the least being an understanding of permafrost as an indicator of climate.

It is interesting that important facts can be learned not only by actual observation and work in the field, but also by intelligent analysis of observations from stations which have the necessary long records. An example of this is the work published by Hare and Montgomery[24]. An examination of temperature records from the west and east coasts of Hudson Bay showed that the east coast was markedly warmer in fall and early winter, whereupon the temperatures became similar around Christmas-time. In spite of the accepted belief that Hudson Bay remained open all winter, it was concluded that the change in east coast temperatures indicated freezing over in late December-early January. From air reconnaissance we now know this to be the case.

It is important that our studies should contribute basic knowledge to the field of arctic meteorology, and environmental studies of climatic conditions may well be undertaken with a view to the underlying physical processes. This kind of study is under way both in the USA and Canada, and in the USSR, based on long-term climatic data and on actual field research. The surface climatic studies are often made to supply the needs of various economic or military activities. They are made, most frequently, with a view to the dependence of the particular activity on meteorological elements. As the technology improves and changes, so also the dependence

on the meteorological elements. Of the greatest importance in environmental research, however, is the investigation of the meteorological elements themselves, basically as functions of solar radiation and the characteristics of the ground surface. Pressure and wind, for example, which are indices of the atmospheric circulation, are functions of the ground structure and the energy available in the form of short wave radiation. So are air temperature and humidity: elements most frequently used in the operational environmental studies. The Russians, especially, have lately called for a deeper study into the connection between the primary climatic components and the surface zonation of natural ground and vegetation covers. There is a close relationship between the principal meteorological elements and the surface fluxes of heat and moisture. It is clear that ground characteristics are factors of the first order in the assessment of surface travel possibilities and also for the taking off and landing of aircraft.

I feel strongly that the Arctic, in summer, needs the flying boat, and freeze-up and break-up dates and duration must be mapped in great detail. The Catalina and even bigger flying boats have an important role to play, and it may be of interest to mention that the British North Greenland Expedition (1952-54) used 4-engine Sunderlands with great success to land on a glacial lake under the snouts of the outflowing glaciers. On the DRB expedition to Lake Hazen, Cansos were used for several summers, and studies of the local climatological conditions and lake water characteristics enable us to forecast the probable ice free season on the lake. From that successful Canadian research programme we have learned many other things about flying weather also in this part of the Arctic. For example, McGill University's observer, C. I. Jackson[25], after 12 months came to regard "bad weather" as "any visibility under 15 miles, or cloud base below 5,000 ft, or wind above 10 mph". 92% of all observations during a year at Lake Hazen had 3 or more miles visibility with a ceiling of 2,500 ft or more. The arctic environment itself does not necessarily place limits on aviation, but it does, of course, add a great many problems, such as maintenance, refuelling etc. With temperatures below –50°F expected for several months, it is obvious that fuel specification is important for surface storage, although a possible storage site exists in arctic lakes, where the temperature of the water is slightly above the freezing point, under a relatively thin ice cover.

Of other surface meteorological conditions affecting aviation, the problems of ice fog and whiteout take on serious proportions. References 26 and 27 discuss ice fog. The warming up and taking off of aircraft can be of critical importance in moisture production. Selection of sites should, if possible, exclude those having topographic depressions, into which air can drain and stagnate. Also, bases should be some distance away and down-wind from the landing area.

"Whiteout" is a peculiar condition sometimes experienced in the Arctic, when visible features and the horizon are indistinguishable. Fritz[30] has recently written on this subject, and states that to explain all the details of the "whiteout" would require an involved psychophysical investigation. Late winter and early spring snow can obliterate surface relief, and with an overcast of a stratus-type cloud there are no shadows. It seems that the surface reflectivity must be above a certain lower limit, approximately 0.6, but there are still many unknowns in this dangerous atmospheric condition which should be given serious attention.

To turn now for a moment to a discussion of stratospheric problems. In the field of stratospheric circulation increasing attention has recently been given to levels between 30,000 and 100,000 ft. McGill University has been engaged in such work for some years, and this work has several direct links with flying operations. One arises from the high concentration of ozone in the lower stratosphere at certain times, which may cause toxic effects for personnel in pressurized aircraft, and may lead to deterioration of rubber and other readily oxidizable materials. High ozone concentrations in the lower stratosphere are known to occur as the result of strong subsidence, the level of maximum ozone concentration being normally in the 70,000 to 90,000 ft layer. Deep cyclones –the so-called "cold lows" – are common in high latitudes, above which strong stratospheric subsidence is usual. In these areas, high ozone concentrations may therefore be expected as low as 40,000 ft, well within the operating range of jet aircraft. Concern has been expressed about the effects of pressurization of such air; it seems unlikely that toxic concentrations could be produced by such means, though it is possible that prolonged exposure to them might be unwise. It does, however, seem possible that rubber and other organic materials may be attacked.

PLANNING

The obvious first step in planning operations in the Arctic, from the meteorological point of view, is to study the chosen area through the existing published weather data. It should be borne in mind that there is a relatively wide variation in meteorological conditions from year to year, resulting for example in ice occurrences which may differ extraordinarily from those of the year before. Also, it is not necessarily legitimate to interpolate between existing weather stations. It may quite possibly be that the operation is of a nature which requires climatological information not normally available, such as certain derived parameters calculated from two or more basic measurements (e.g., windchill). Most of such combinations can be machine calculated from prepared cards containing the standard observations, but enough time should be allowed for such preliminary studies.

It may not be possible to obtain a statement of weather conditions for a particular route or site in the Arctic, and a reconnaissance to the area may give valuable clues to the careful observer. On the preliminary flight to Lake Hazen, for example, it was judged from observations of the snow cover on the lake ice that winds would seldom be more than 5 mph, and annual precipitation should not amount to more than a few inches. This proved to be true for the 1957-58 year of occupation.

Getting a local forecast, however, is some time off for sites removed from the regular stations. "Objective forecasting" is usually done by applying empirical rules

to meteorological data, and such techniques have seldom been developed for arctic areas, except for some cases in Alaska. Jackson[31] is of the opinion that they may be of considerable use for the Joint Weather Stations. The other method of preparing a local forecast is by a combination of statistical and synoptic techniques. The average results of various synoptic developments are analyzed, and if subsequent analogous situations are recognized, the forecaster can study the previous developments. These methods, however, both need several years of continuous records. Observations from a site occupied for only a short period may allow the extraction from the short record of those features which are likely to be true of most years. If they are arranged in a form which may be of use to the forecaster, one can file them and refer to them at a later time, if further operations are planned in the area. Such local files, however, would require occupation of many sites within the high Arctic for limited periods, and this is where we stand today: many local areas are still unknown, and from a meteorological point of view it is desirable that the exploration of the Arctic continue for many years to come.

REFERENCES

(1) Hare, F. K. – *The Disturbed Circulation of the Arctic Stratosphere*, Jour. of Met., Vol. 17, No. 1, February, 1960.

(2) Hare, F. K. – *The Observed Summer Circulation of the Arctic Stratosphere Below 30 km*, Quart. Jour. R. Met. Soc., Vol. 86, 1960.

(3) Hare, F. K., and Orvig, S. – *The Arctic Circulation*, Arctic Met. Res. Group, Publ. in Met., No. 12, June, 1958.

(4) Namias, J. – *The General Circulation of the Lower Troposphere Over Arctic Regions and its Relation to the Circulation Elsewhere*, Polar Atm. Symposium, Part I, Pergamon Press, 1958.

(5) Chiu, Wan-Cheng – *The Observed Mean Monthly Wind Fields in the Lower Stratosphere and Upper Troposphere Over North America*, Jour. of Met., Vol. 15, No. 1, February, 1958.

(6) Godson, W. L., and Lee, R. – *High-Level Fields of Wind and Temperature Over the Canadian Arctic*, Beitr. zur Phys. der Atmos., Vol. 31, 1958.

(7) Reiter, E. R. – *The Layer of Maximum Wind*, Jour. of Met., Vol. 15, No. 1, February, 1958.

(8) Wexler, H., and Moreland, W. B. – *Winds and Temperatures in the Arctic Stratosphere*, Polar Atm. Symposium, Part I, Pergamon Press, 1958.

(9) Warnecke, G. – *Ein Beitrag zur Aerologie der arktischen Stratosphäre*, Met. Abhand., Vol. 3, No. 3, 1956.

(10) Craig, R. A., and Hering, W. S. – *The Stratospheric Warming of January-February 1957*, Jour. of Met., Vol. 16, No. 2, April, 1959.

(11) Godson, W. L. – *A Comparison of the Winter-Summer Transitions in the Arctic and Antarctic Stratosphere*, paper read at meeting of Royal Met. Soc., Can. Branch, Kingston, Ont., June 8th, 1960.

(12) Ohring, G. – *The Radiation Budget of the Stratosphere*, Jour. of Met., Vol. 15, No. 5, October, 1958.

(13) Scherhag, R. – *Die Explosionsartigen Stratosphären-Erwärmungen des Spätwinters 1951-52*, Ber. Deutsch. Wetterdienst, Vol. 6, 1952.

(14) Teweles, S. – *Anomalous Warming of the Stratosphere Over North America in Early 1957*, Mon. Wea. Rev., Vol. 86, 1958.

(15) Lee, R., and Godson, W. L. – *The Arctic Stratospheric Jet-stream During the Winter of 1955-56*, Jour. of Met., Vol. 14, No. 2, April, 1957.

(16) Keegan, T. J. – *Arctic Synoptic Activity in Winter*, Jour. of Met., Vol. 15, No. 6, December, 1958.

(17) Reed, R. J. – *Arctic Weather Analysis and Forecasting*, Report No. 7, Univ. of Wash., 1959.

(18) Scherhag, R. – *The Role of Tropospheric Cold-Air Poles and of Stratospheric High-Pressure Centers in the Arctic Weather*, Polar Atm. Symposium, Part I, Pergamon Press, 1958.

(19) Boville, B. W., and Hare, F. K. – *Total Ozone and Cold Lows in the Middle Stratosphere*, paper read at meeting of Royal Met. Soc., Can. Branch, Kingston, Ont., June 8, 1960.

(20) Mateer, C. L. – *The Vertical Distribution of Atmospheric Ozone in Canada*, paper read at meeting of Royal Met. Soc., Can. Branch, Kingston, Ont., June 8, 1960.

(21) *Temperature and Wind Frequency Tables for Eurasia*, Vol. 1, January-March, Arctic Met. Res. Group, Publ. in Met., No. 18, February, 1960.

(22) Dunbar, M. – *The Pattern of Ice Distribution in Canadian Arctic Seas*, Trans. R. Soc., June, 1954.

(23) *Pilot of Arctic Canada*, Canadian Hydrographic Service, Vol. I, Ottawa, 1959.

(24) Hare, F. K., and Montgomery, M. R. – *Ice, Open Water and Winter Climate in the Eastern Arctic of North America*, parts I and II, Arctic, Vol. 2, Nos. 2 and 3, 1949.

(25) Jackson, C. I. – *The Meteorology of Lake Hazen, N.W.T., Part I: Analysis of the Observations*, Arctic Met. Res. Group, Publ. in Met., No. 15, August, 1959.

(26) Appleman, H. – *The Cause and Forecasting of Ice Fogs*, Bull. Am. Met. Soc., Vol. 34, 1953.

(27) Mitchell, J. M. – *Visual Range in the Polar Regions, with Particular Reference to the Alaskan Arctic*, Polar Atm. Symposium, Part I, Pergamon Press, 1958.

(28) Court, A. – *On the Arctic Whiteout*, Bull. Am. Met. Soc., Vol. 27, 1946.

(29) Hedine, L. – *The Arctic Whiteout*, Bull. Am. Met. Soc., Vol. 27, 1946.

(30) Fritz, S. – *On the "Arctic Whiteout"*, Polar Atm. Symposium, Part I, Pergamon Press, 1958.

(31) Jackson, C. I. – *The Meteorology of Lake Hazen, N.W.T., Part III: Local Forecasting*, Arctic Met. Res. Group, Publ. in Met., No. 16, April, 1960.

CANADIAN AERONAUTICAL INSTITUTE

RADIAL GRIDS WITH WATER INJECTION FOR SUPPRESSING THE NOISE OF JET ENGINES†

by H. U. Wisniowski*

National Research Council

SUMMARY

Noise-suppression experiments were made with water sprays introduced into the stream of exhaust gases from a jet engine, by means of radial grids with tubular perforated arms. This method proved to be very satisfactory for the test cell installation with an appreciable length of exhaust duct. An over-all noise-level reduction of 31.5 db was obtained at a water flow rate of 259 Imp gal/min for a jet engine of 100 lb/sec mass flow.

In the field installation, the method was found less attractive, because of the necessity of using a rather long exhaust duct to obtain higher noise attenuation.

It was shown that a cylindrical shroud mounted on the grid suppresses the noise (called "hoot") produced when the grid is mounted too far from the engine final nozzle.

INTRODUCTION

The experiments were made as a part of the program to suppress the noise from jet engines running in the test cells of the Engine Laboratory.

Injection of water into the exhaust of jet engines, in order to reduce the noise, has already been tried in test cells, as well as in field installations[1, 2, 3]. The sound attenuation by water sprays is due to the viscous losses in the air or other gases caused by their movement around the suspended water droplets[2]. This attenuation depends on such factors as the amount of water, the size and distribution of the water droplets, the density and viscosity of the gases, gas velocities, temperature gradients, length of the spray chamber etc. Theoretical calculations can be found in References 4 and 5. Concluding, it can be said that the phenomenon is complex, and the effectiveness of a particular water-spray system cannot be readily predicted at the present state of knowledge.

Summaries of the results obtained in test cells by other investigators are given in References 2 and 6. However, the water flow rates necessary for appreciable noise reductions were so high that they may be prohibitive, at least for continuous operation. The devices usually applied were, according to Reference 7, single or multiple spray rings.

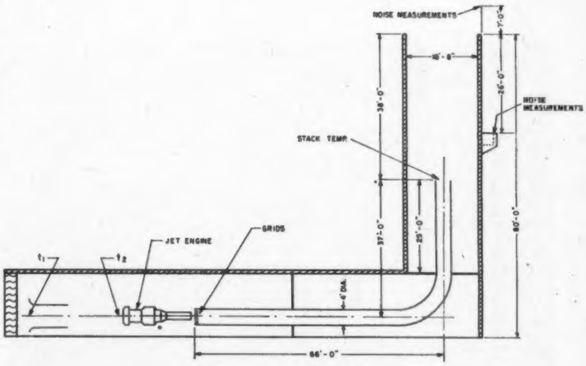

Figure 1
Diagrammatical sketch of general test cell installation

On the basis of previous experiments (Reference 8, tests on a grid with cut-out centre) it is believed that the core of the jet plays an important part in noise generation. Consequently, to be effective, the water sprays must penetrate to this core. If tubular rings, with holes or nozzles spraying radially towards the centre, are used, very large holes and high water pressure must be applied to achieve a good penetration because the engine exhaust jet deflects the sprays. This, of course, results in enormous water flow rates if appreciable noise attenuation has to be obtained.

In the present experiments, water was introduced into the core of the jet by means of radial grids with perforated tubular arms. In this manner the necessity of using large holes and high water pressure was obviated. The present report describes the investigation of this method.

INSTALLATION

Test cell installation

A diagrammatical sketch of the general test cell installation is shown in Figure 1. Under standard conditions (15°C, 30 inches Hg), the jet engine used for tests developed 5000 lb thrust at 7500 rpm. The final nozzle diameter was 20¼ inches, and the nozzle pressure ratio (total to barometric) was 1.64. The tailpipe

†Paper based on N.R.C. Report LR-281
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temperature was 656°C. The temperature at the outlet of the exhaust duct was 284°C (it was called "stack temperature"). The inlet air temperature t_1 was read in the section of ducting about 24 ft from the engine. The temperature close to the engine t_2 was also measured to check the re-circulation of hot exhaust gases which would take place if the blockage of the exhaust duct by the noise suppressor was too high. The total length of the exhaust duct was approximately 100 ft, and the outer diameter 4 ft (wall thickness 0.25 inches).

For noise measurements, the engine was run at 7500 rpm (observed) and for any test or series of tests a calibration run without any suppressor was made under the same atmospheric conditions.

The gases were exhausted vertically from a concrete stack — 18 ft 8 inches × 20 ft 8 inches and 80 ft high (Figure 2). As the sound field can be assumed symmetrical around the jet axis[7], acoustic measurements at a single station were considered to give sufficient information for comparison of the suppressors tested. Preliminary measurements[8] included pressure spectra of sound and over-all sound-pressure levels taken 7 ft above the outlet of the concrete exhaust stack and on the balcony (Figure 1) 8 ft above the highest adjacent roof. At those two stations the sound spectra were similar, and the sound-level reductions obtained with the suppressors were the same. For subsequent measurements the station on the balcony was chosen as more accessible, less exposed to the water mist and sufficiently high to avoid much of the influence of surrounding buildings and interfering noise from other sources.

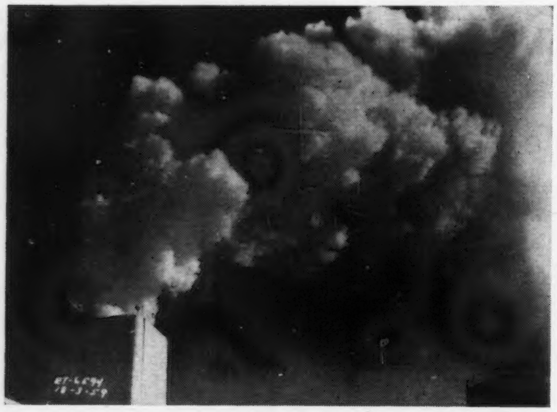

Figure 2
The cloud from the stack of the test cell during experiments with water injection

Water was supplied first by the test cell installation, the capacity of which was up to about 200 Imp gal/min, depending on local conditions. Later, an outside fire hydrant was used. The available rate of flow was also, in this case, not consistent and amounted to about 270 Imp gal/min under pressure of 54 psi at the fire hydrant. The connecting fire hose of 2½ inches diameter was approximately 100 ft long. Water flow was measured by a 3 inch Neptune water meter.

Figure 3
Field installation

The over-all sound-pressure level of the engine without any noise suppressor was 108 db at the station on the balcony, plus or minus 1 db depending on atmospheric conditions.

The measurements of the over-all sound-pressure level (also referred to as sound or noise level) were made with the sound-level indicator, Type 1408-B, Dawe Instruments Ltd. (England); the scale *C* ("flat") was always used. An Ampex, Model 601, Magnetic Tape Recorder (USA) and an Audio Frequency Spectrometer, Type 2109, Bruel and Kjaer (Denmark) were used to obtain the pressure spectra of sound (also referred to as sound or noise spectra).

For measuring the frequencies of hoot, an Ampex, Model 620, Amplifier-Speaker and Beat Frequency Oscillator, Type 1014, Bruel and Kjaer, were used.

Field installation

This arrangement is shown in Figures 3 and 4. The engine and grids were mounted on the portable frame. Later, an exhaust duct of 40 inches outside diameter (wall thickness 0.25 inches) and of 20 ft 10 inches in length was added. The same jet engine was used but its speed was reduced to 7150 rpm (observed) because of limitations of the fuel supply pump. This pump was an integral part of the 1500 Imp gal tank truck. The jet engine was started by a Comstock starter driven by a gasoline motor. No thrust-measuring facilities were provided.

Water was supplied by a fire hydrant, and the same 3 inch Neptune water meter was used.

Polar diagrams of noise at a 200 ft distance from the engine final nozzle were made. The initial measurements with the sound-level indicator showed rather high oscillations, which affected the reliability of readings, and subsequently the sound was recorded with the Ampex, Model 601 Magnetic Tape Recorder.

Figure 4
Field installation with exhaust duct

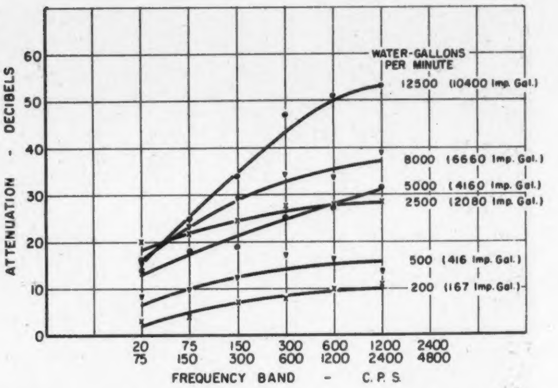

Figure 5
Summary of the sound attenuation measured through several water-spray systems as a function of octave frequency bands with gallons of water sprayed per minute as a parameter (from Reference 2)

For further evaluation a Type 1550-A, Octave-Band Noise Analyzer, General Radio Co. (USA) and a Level Recorder, Type 2304, Bruel and Kjaer, were used.

All of the more complicated acoustical measurements during the experiments were supervised by Mr. Weibust.

TEST RESULTS AND DISCUSSION

Experiments in the test cell

In order to check the results obtained by other investigators with conventional installations[2] (Figure 5), a water-spraying ring was made and mounted in the inlet of the exhaust duct of the test cell, 9 inches from the final nozzle of the jet engine (Figure 6). The ring was made from 2 inch pipe, had an inside diameter of 30 inches and 48 holes of ⅜ inch diameter, spraying towards the centre.

First runs were made during the colder season and with water supplied by the test cell installation. As can be seen in Figure 7, the highest noise attenuation obtained was 10½ db with maximum water flow of 196.5 Imp gal/min available at the time. The outside temperature was about +5°C. Later, the measurements were made at a higher outside temperature (about

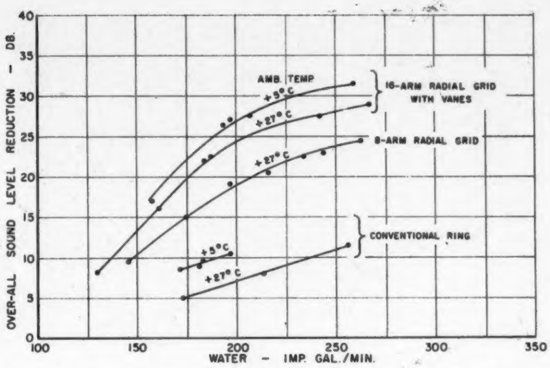

Figure 7
Jet engine noise suppression by radial grid with water injection as compared with conventional ring

+27°C) and with a higher water flow rate from the fire hydrant. The maximum noise-level attenuation obtained under these conditions was 11½ db with 256 Imp gal/min of water.

It can be seen in Figure 7 that the outside temperature influenced the noise attenuation, the lower temperature being more advantageous. In a given case, the temperature rise of 22°C reduced the noise attenuation by about 3½ db. This may indicate that the water mist is more effective in noise attenuation than the vapour. However, in both cases, the stack temperature was well below the boiling point (about 53°C, with only a few degrees difference in both cases), so that the above statement concerns only the conditions in the exhaust duct.

For comparison with results of other investigators, the curve for 167 Imp gal/min of water in Figure 5 may be used, which shows the attenuation obtained between 3 and 10 db, depending on frequencies. The over-all sound-level reduction was, in this case, somewhere between 3 and 10 db. This gives the same order of attenuation as obtained with the tested ring for the same water flow, namely between 4½ and 8 db for outside temperatures between 5° and 27°C (Figure 7).

As mentioned before, the leading idea of the present experiments was to introduce water sprays into the core of the stream of exhaust gases from the jet

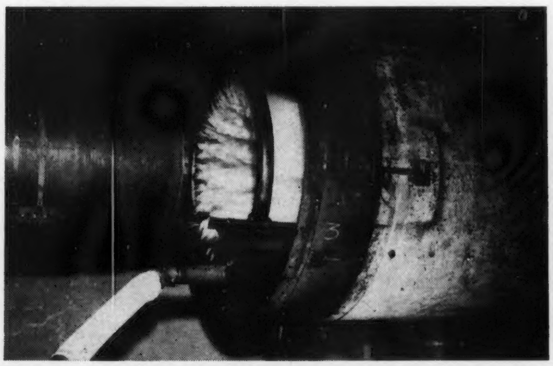

Figure 6
Water-spraying ring

Figure 8
16-arm radial grid with vanes

Figure 9
16-arm radial grid with vanes

engine. For that purpose the radial 16- and 8-arm grids were used, as shown in Figures 8 to 11*.

The grids consisted of a ring of 30 inches inside diameter, made from 2 inch pipe, and of tubular arms with spraying holes on both sides drilled in the plane of the grid. In the case of the 16-arm grid, the arms were made from ¾ inch outside diameter tubes of 1/16 inch wall thickness. They had ten holes of ⅛ inch diameter on each side, spaced at 1.0 inch.

The arms of the 8-arm grid were made from 1.0 inch outside diameter tubes of 1/16 inch wall thickness. The holes (also ten on each side) had a 3/16 inch diameter, and spacing was 1 5/16 inches.

The grids had to be specially designed to avoid cracking due to temperature changes and resulting expansion and contraction. Cutting the arm tubes shorter than the inside radius of the ring and supporting them by vanes proved to be one satisfactory design (Figure 9). The vanes were welded to the ring and the tubes were attached to them by one clamp each, thus being allowed to expand and contract.

In another design the arm tubes were clamped between two parts of a streamlined "centre hub", retaining also the freedom of movement in a radial direction (Figures 10 and 11). The diameter of the hub was, in this case, 3 inches and the total length 6½ inches.

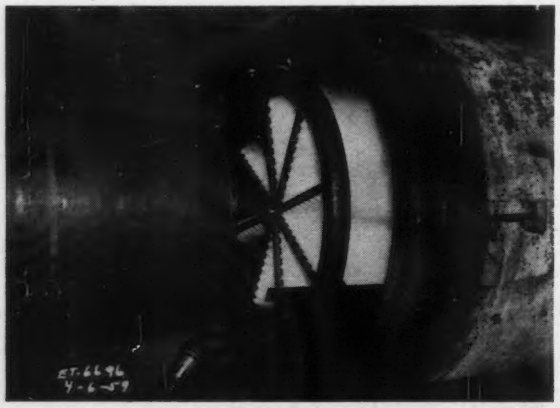

Figure 10
8-arm radial grid with centre hub

*Patents pending.

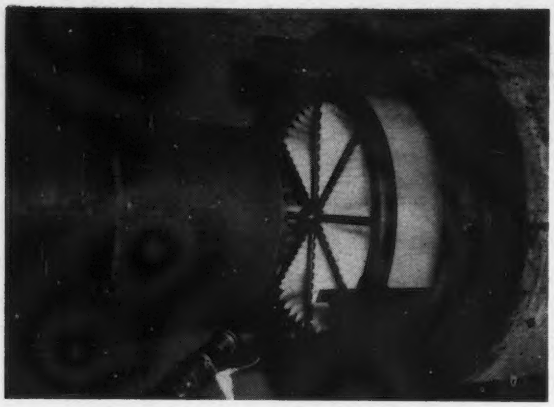

Figure 11
8-arm radial grid with additional holes in the ring

The 16-arm grid was tested first, and the experiments started during the colder season. With a maximum available water flow of 259 Imp gal/min from the fire hydrant, the reduction in over-all noise level was very satisfactory, amounting to 31½ db (Figure 7).

The repeated measurements in warmer weather, with outside temperature about +27°C, resulted in about 3 db lower attenuation at higher water flow rates (Figure 7), thus showing the same influence of outside temperature as was found with the water-spraying ring.

The noise spectrum is presented in Figure 12. For all most important frequencies, that is, from the lowest up to about 1000 cps, the reduction of the sound-pressure level was very good and amounted to as much as 32 db at 125 cps.

The noise attenuation obtained by the 16-arm grid alone (with no water) was 9 db. It can be seen in Figure 7 that for 130 Imp gal/min of water, the attenuation was 8 db only, which means that using too small a rate of water flow not only fails to improve the attenuation but even causes it to deteriorate. Some more measurements at less than the above water rates were made and, though the results were scattered, all of them showed still less attenuation. No satisfactory

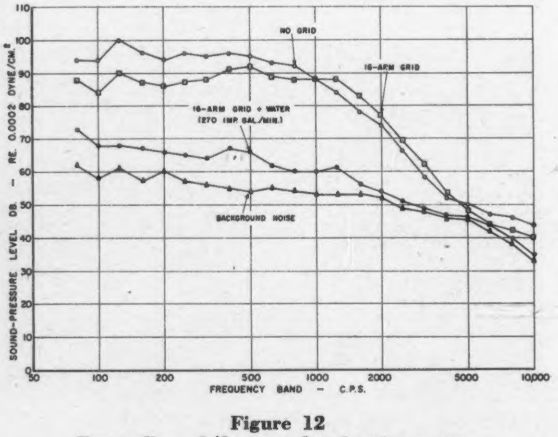

Figure 12
Test cell — 1/3 octave-band noise spectra

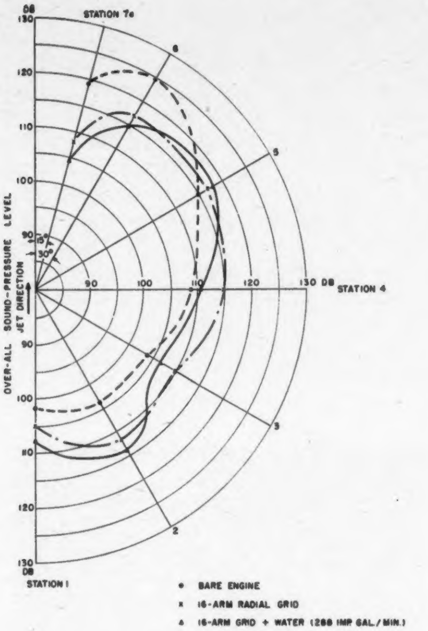

Figure 13
Field installation — over-all sound-pressure levels at a 200 ft distance

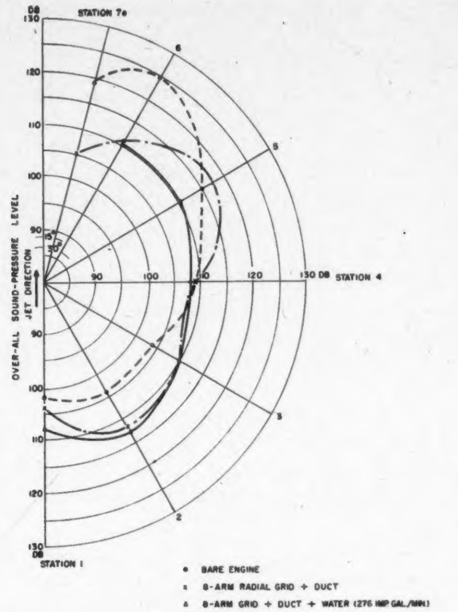

Figure 14
Field installation — over-all sound-pressure levels at a 200 ft distance

explanation of this phenomenon can be offered at this time.

The 16-arm grid did not affect the tailpipe temperature and the thrust of the jet engine, whether running dry or with water injection. However, it was known from experience with other engines that some of them are more sensitive in this respect than others. It was, therefore, of interest to investigate an 8-arm grid (Figures 10 and 11), the blockage area of which was only about half of that of the 16-arm one.

The result is shown in Figure 7. At higher water rates the attenuation curve lies about 4 to 5 db lower than the curve for the 16-arm grid, and the maximum obtained was 24.5 db at 263 Imp gal/min of water. This means that the 8-arm grid also gave very attractive results.

The effect of additional peripheral holes in the ring was investigated on this grid. Forty holes of 3/16 inch diameter, spaced at 1¾ inches, were drilled (Figure 11). The effect was found to be negligible.

The noise attenuation by the 8-arm grid alone (running dry) was 8 db.

Field experiments

The results of these tests are shown in polar diagrams, Figures 13 and 14, taken at a 200 ft distance from the engine final nozzle.

First, the 16-arm grid without water was tried (Figure 3). The maximum noise-level reduction was 11 db at station 7a, 15° from the axis of the exhaust, but at stations 1 to 5 the noise level was higher, amounting to an 8 db increase at station 2 (Figure 13).

Use of water at the rate of 288 Imp gal/min showed only a moderate improvement, the maximum additional reduction being 4 db at station 4. The maximum total reduction with water was 14 db at station 7a.

In comparison with attenuation in the test cell, the result obtained indicated that the exhaust duct plays the important part in the method of noise suppression by water sprays. Accordingly, a 20 ft, 10 inch-long exhaust duct of 40 inches outside diameter was installed (Figure 4). This time an 8-arm grid was used as it was lighter and easier to handle.

As can be seen in Figure 14, the maximum in noise-level reduction obtained with the grid and duct (no water) was 14 db at stations 6 and 7a, changing to an increase of noise level at stations 1, 2, 3 and 5. The main effect of water injection at a rate of 276 Imp gal/min was cutting the highest peak of the curve at station 5 by 7 db.

The noise spectrum at this station is shown in Figure 15. It differs from that obtained in the test

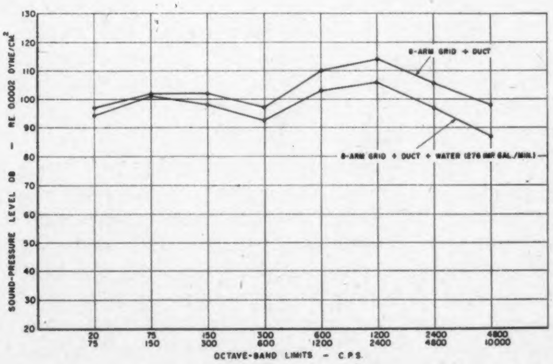

Figure 15
Field installation — octave-band noise spectra at station 5

cell (Figure 12) not only by the amount of noise reduction but also by an increase of this reduction with higher frequencies.

The time available for field tests was limited and no further experiments were made. It is probable that the addition of a 90° elbow, with some length of the vertical duct as well, might have improved the results obtained. However, this arrangement would then have become rather cumbersome for a field installation.

Noise of grids (hoot)

The grids caused a peculiar noise, called a hoot, when installed too far from the engine final nozzle. This had been experienced during previous experiments[8]. The noise is radiated by the grid itself; its origin cannot be in the exhaust duct or in the tail pipe, since it was obtained both in field installations, with no exhaust duct (Reference 9 and the present investigation), and on the engine with the tail cone only and no tail pipe.

The test procedure for investigating hoot was to run the engine from idle to maximum speed (observed) and back to idle again. The grid investigated was mounted in a position farther from the engine final nozzle than was accepted as optimum. This position, giving hoot, was 15 inches from the final nozzle for the grids in question.

Both grids, 16-arm and 8-arm, showed similar hoot characteristics. At about 5900 rpm (observed) the trace of hoot started. At about 6750 rpm, the strong high pitch began, being most pronounced at about 7000 rpm. At about 7150 rpm, the pitch changed to the lower one and was intensified up to the maximum engine speed of 7500 rpm. The frequency of hoot measured at 7000 rpm was 750 cps and at 7500 rpm, 500 cps.

It had been suggested before[8] that the phenomenon was associated with vortex shedding from, and wake fluctuation behind the rods of the suppressor, and that it was of a type similar to the so-called Aeolian Tones (see, for instance, Reference 10). Accordingly it was hoped that injecting water from the holes in the tubular arms would suppress, or at least influence this phenomenon[11]. The contrary was found, and absolutely no effect was noticeable, even when additional water-spraying holes on the rear side of the arms were drilled.

Similarly with the fins supporting the arms of the radial grid (Figures 8 and 9); they were made especially wide (6 inches) to affect the vortex shedding process from the grid arms, but not the smallest difference in the phenomenon was observed.

A Schlieren apparatus was available, and much effort was spent by Mr. Rodkiewicz in examining the flow around and behind the grid arms to find an explanation of the hooting, but no conclusive result was obtained. Finally the tuft method was tried and after asbestos tufts had failed, being torn too quickly, stainless steel wire at last proved satisfactory. They were attached to the arm by means of loops in every second spraying hole and could move freely in the stream of exhaust gases.

It can be seen in Figure 16 (exposure time 4 sec) that the first three tufts from the centre of the grid (part of the centre hub is visible at the top of the photograph) indicate some transverse components of flow, the first and second tufts deflecting in the opposite direction to the third. On the assumption that this might be the origin of irregularities in the flow leading to hoot, a cylindrical shroud was made and attached to the grid in order to counteract the transverse components of the flow. The diameter of the shroud was chosen as 14 inches so that the cylinder wall was located just in between the second and third tufts. The length of the shroud was 12 inches (Figure 17 shows a similar shroud 5 inches long). With this shroud a hoot-free run up to the speed of 7150 rpm was obtained, the higher pitch being thus eliminated.

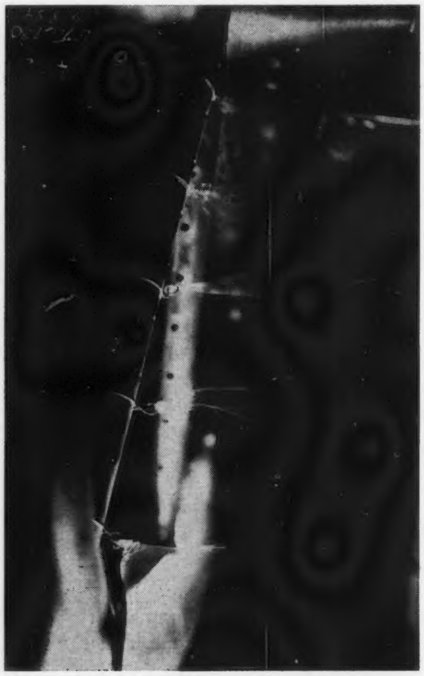

Figure 16
Steel wire tufts used to visualize the gas flow

The following shrouds were tried:

	Inside diameter (inches)	*Length (inches)*	
1a	14	12	
2a	20	12	
3a	10	12	
4a	14	8	
5a	14	5	(Figure 17)
6a	35½	8	(Coinciding with the outer diameter of the tubular ring of the grid)

The shrouds were made from inconel 1/16 inch thick. All shrouds were tested with an 8-arm radial grid.

Shroud 2a was even worse than the grid alone, giving hoot over practically the whole range of engine

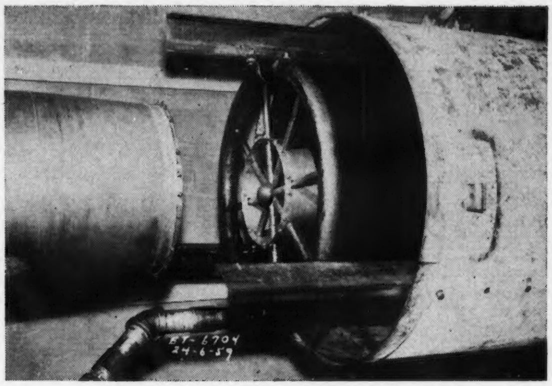

Figure 17
Solid anti-hoot shroud

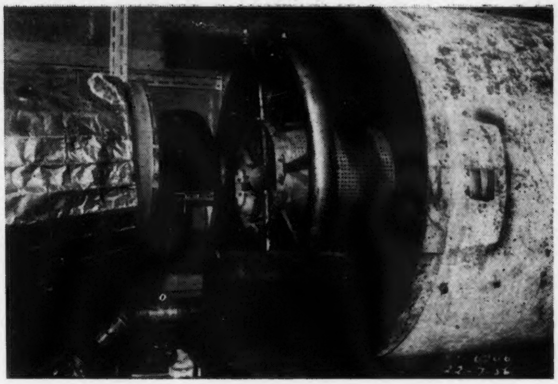

Figure 18
Perforated anti-hoot shroud

speed. 3a was little worse than 1a, not eliminating entirely the higher pitch. 6a had no effect on hoot. In this manner it was proved that the first choice of the 14 inch diameter shroud, based on the flow pattern indicated by wire tufts, was right.

Shrouds 4a and 5a were tested to determine the best length of the 14 inch-diameter shroud, and the length of the 8 inch (4a) was found to be the optimum, suppressing hoot up to 7250 rpm.

The shrouds were tested without water and with it. No marked effect of water injection was observed.

Next, the perforated and partially perforated shrouds, as specified below, were tested. All of them were of 14 inch inside diameter and the holes were always made on ½ inch centres.

	Diameter of holes (inches)	*Length of Shroud (inches)*	
1b	3/16	8	all perforated
2b	3/16	21	all perforated
3b	3/16	16	all perforated
4b	⅛	16	all perforated
5b	⅛	12.5	all perforated
6b	⅛	9	all perforated
7b	¼	16	all perforated
8b	¼	13	all perforated
9b	3/16	8	solid, and
		8	perforated (Figure 18)
10b	3/16	8	solid, and
		13	perforated
11b	3/16	8	solid, and
		10	perforated

Shroud 1b showed improvement in comparison with the similar solid shroud (4a). Running dry, it was effective up to the speed of 7250 rpm, like the solid shroud; but with water injection, it eliminated hoot up to 7400 rpm. It was the general characteristic of perforated shrouds that they were more effective with water injection. The water injected by the grid formed a kind of cover on the perforations, apparently improving their damping effect.

2b and 3b were tested in order to determine the best length of the shroud. The length of 16 inches (3b) was found to be the best, giving a hoot-free run up to 7400 rpm without water. Use of water markedly reduced the hoot from 7400 to 7500 rpm.

Smaller perforations of ⅛ inch diameter were tried on shrouds 4b, 5b and 6b, but they were found to be less effective than 3/16 inch holes. The same was found with larger holes of ¼ inch diameter on shrouds 7b and 8b.

Some of the shrouds tested were made of two pieces, allowing the change of length in a telescopic manner. By turning these two pieces against each other, some of the holes could be covered. Following some observations on such shrouds, the shrouds combined from a solid part and a perforated one were tested. Shroud 11b, consisting of an 8 inch length of solid part and a 10 inch length of perforated part, showed the best results, eliminating the hoot up to 7400 rpm when running dry, and leaving only a trace of hoot at maximum speed of 7500 rpm with water injection.

The failure of water sprays and fins behind the arms of radial grids in influencing hoot would discount the previous suggestion that the phenomenon is connected with vortex shedding and so-called Aeolian Tones.

Classical acoustics[12, 13] deals with three types of basic or pure types of gas oscillations which can occur in a cylinder:

(a) longitudinal or organ-pipe oscillation, characterized by an axial motion of gas particles,
(b) transverse oscillation, when gas particles move from wall to wall, and
(c) radial oscillation, when gas particles move from the axis of the cylinder towards the walls and backwards.

The difficulty in applying the theory is that the hoot was found to be independent of the tailpipe or exhaust duct, so that there was no cylinder which could be referred to. Furthermore, the classical formulae for frequency of oscillation include the sonic velocity of gases which, as is well known, depends on temperature. These temperatures were different when the grid was run dry and with water injection, but in both cases the frequency of hoot was the same.

However, in spite of the lack of dependence on temperature, it may perhaps be concluded from the effect of cylindrical shrouds on hoot that the oscillations in question are of a radial type, the transverse type being excluded by failure of fins to influence this phenomenon. Such fins would have an effect on transverse oscillations as was previously found[11].

CONCLUSION

The method of introducing water sprays into the exhaust stream of gases of a jet engine by means of radial grids proved to be very satisfactory for noise attenuation in the test cell installation with exhaust duct of appreciable length.

The maximum noise-level reduction obtained amounted to 31.5 db with a flow rate of 259 Imp gal/min, which was still acceptable. This rate was about 10 times smaller than that necessary with conventional installations to obtain the same attenuation.

In comparison with dry silencer systems giving the same order of noise-level reduction, the cost of the water-spraying installation is about 100 times lower.

For the field installation, the method was found to be less attractive, because of the necessity of using a rather long exhaust duct to obtain higher noise attenuation.

Cylindrical shrouds mounted on the grid were found to be effective in preventing hoot.

REFERENCES

(1) Richards, E. J. – *Research on Aerodynamic Noise from Jets and Associated Problems,* Jour. Aero. Soc., Vol. 57, No. 509, p 318-42, May, 1953.

(2) Watters, B. G., Labate, S., and Beranek, L. L. – *Acoustical Behaviour of Some Engine Test Cell Structures,* Jour. Acoust. Soc. of Am., Vol. 27, No. 3, p 449-56, May, 1955.

(3) Kurbjun, M. C. – *Limited Investigation of Noise Suppression by Injection of Water into Exhaust of Afterburning Jet Engine,* NACA RM L57L05, February, 1958.

(4) Knudsen, W. O., Wilson, J. V., and Anderson, N. S. – *The Attenuation of Audible Sound in Fog and Smoke,* Jour. Acoust. Soc. of Am., Vol. 20, No. 6, p 849-57, November, 1948.

(5) Epstein, P. S., and Carhart, R. R. – *The Absorption of Sound in Suspensions and Emulsions. I. Water Fog in Air,* Jour Acoust. Soc. of Am., Vol. 25, No. 3, p 553-65, May, 1953.

(6) Harris, C. M. – *Handbook of Noise Control,* McGraw-Hill Book Co. Inc., Chap. 34, p 27, 1957.

(7) Bolts, R. H., ed. – *Handbook of Acoustic Noise Control,* Vol. 1, WADC Tech. Rep. 52-204, December, 1953.

(8) Wisniowski, H. U. – *Experiments with Screens and Grids for Suppressing Jet Engine Noise,* NAE Lab. Rep. LR-231, October, 1958.

(9) Callaghan, E. E., and Coles, W. D. – *Investigation of Jet-Engine Noise Reduction by Screens Located Transversely Across the Jet,* NACA TN 3452, May, 1955.

(10) Etkin, B., Korbacher, G. K., and Keefe, R. T. – *Acoustic Radiation from a Stationary Cylinder in a Fluid Stream (Aeolian Tones),* Institute of Aerophysics, Univ. of Toronto, Report No. 39, May, 1956.

(11) Wisniowski, H. U. – *Investigation of Screeching Combustion and Means of Preventing It,* NAE Lab. Rep. LR-147, June, 1955.

(12) Rayleigh, J. W. S. – *The Theory of Sound,* Dover Pub., N.Y., 1945.

(13) Morse, P. M. – *Vibration and Sound,* McGraw-Hill Book Co. Inc., N.Y., 1948.

TECHNICAL FORUM

Long Range Communication with Aircraft†

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PERHAPS the most difficult problem in aircraft communications is that of ground to air communications at distances beyond line of sight, just over the horizon to some thousands of miles. This paper will review some of the possible methods of long range communications with aircraft and point out the advantages and disadvantages of each method.

A communication system consists of a number of component units all of which together make for a successful operation. Installation in aircraft imposes restrictions on physical size and power which affect the efficiency of such systems. The greatest problem is not in the transmitting and receiving equipment but in mounting, on the aircraft, efficient transmitting and receiving antennas. Two other factors which are extremely important, but sometimes forgotten in our efforts to design new and sophisticated equipments, are, firstly, the radio propagation characteristics between transmitter and receiver, and, secondly, the efficiency and judgment of the radio operator. When installing ground-based communication circuits, these problems can be minimized by such design at considerable expense, of course. On the other hand, both space and power are limited in aircraft so that propagation factors and operator efficiency assume a greater importance.

Our knowledge of radio propagation has advanced greatly, and communication systems are practical now which were not conceived fifteen years ago. It is worthwhile to discuss the possible methods from a physical and engineering point of view, although implementation may be limited by available frequency assignments or other factors.

Much long distance communication with aircraft is carried on in the high frequency band (3-25 mc/sec, approximately). In this range, communications equipment is readily available. Radiators for transmission and reception in aircraft may be simple wire antennas of reasonable size. Such antennas are not very directive, and much energy is radiated by the transmitter in other than the wanted directions and the aircraft receiver picks up unwanted interfering signals.

Beyond the line of sight one depends upon reflections of the radio signals by way of the ionospheric layers, 100-300 km above the surface of the earth. The bands of frequencies which may be used for communication between two points, using this mode of propagation, are dependent upon the time of day (higher frequencies in daytime, lower at night) and seasonal variations (daytime usable bands in December extend over about twice the frequency range that is available in the summer). The usable band also varies with distance between aircraft and ground station.

It could be concluded that use of this range of frequencies is too unreliable with too many variables to consider. We have no better alternative at present, however, and the comparative simplicity and availability of equipment is not to be ignored. I shall return to this discussion later.

In shipping circles it is well known that over sea paths radio transmission on frequencies below about 5 mc/sec will propagate reliably well beyond the horizon; the lower the frequency the farther the ground wave is propagated. Unfortunately, the propagation distances over land are much less than that over sea and are more variable due to irregular electrical conductivity of the ground. However, with suitably powerful, ground transmitters and antenna arrays, long distance reception, in aircraft, may be quite good and reliable even with the limitations imposed by aircraft on such antennas. Medium frequency beacons and Loran are examples. Recent development of ferrite core types of antennas can increase the efficiency of reception but a requirement for two-way communication would necessitate transmitting equipment and antennas difficult to install in aircraft.

At very high frequencies (20-70 mc/sec approximately), but generally below frequencies used by aircraft for line of sight communications and modern radar and navigational equipment, propagation characteristics are not always simple. Above the upper limits of ionospherically reflected propagation it is possible, with reasonable transmitting power, to communicate beyond the horizon, by reflection or scattering from small discontinuities in the atmosphere. The significant discontinuities are in the form of meteor trails and sporadic blobs of ionization at 60-120 km altitude.

Uninterrupted communications using these modes are not possible, but sufficient knowledge of the char-

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*Superintendent, Communications Laboratory

acteristics and occurrence of reflections off meteor trails is known to make the meteor reflection system practical for ground-to-air as well as between ground stations separated by distances of the order of 500-1500 miles. Ground-to-air communication, as in other systems, is not a great problem. Encouraging studies of air-to-ground transmission by the meteor reflection system have been done.

On the higher frequencies, above 100 mc/sec or so, scatter propagation is possibly by way of discontinuities in the troposphere. The reliability of communications is high as long as frequencies which are affected by water vapour, attenuation or reflection, are avoided. Since propagation is by scattered signal, high transmitter powers and large directive antennas are required. The problem of orientation, with respect to a ground station, of a narrow beam antenna on an aircraft is great. As with low frequency communication, satisfactory reception is a much easier achievement than transmission.

We conclude that the low frequencies and the very high frequencies are probably the best answer for reception in aircraft to some hundreds of miles, but for two way communication we resort to high frequency communication using reflections from the ionosphere, remembering, however, the potential of the meteor reflection system.

The choice of a suitable frequency in the HF band is complicated by:

(a) varying distance between transmitter and receiver,
(b) temporal variability of reflection characteristics of the ionosphere, and
(c) ionospheric disturbances.

The first two variables may be taken into account by an understanding of the reflection modes due to the ionosphere. Frequencies are adjusted according to a pattern determined by time of day, year and distance between aircraft and ground station. Such information can be worked out in advance for any flight plan, or on a routine basis for established routes. Often the difficulties in maintaining such communications are due to the tendency on the part of the radio operator to stick to a frequency which has been known to be usable in some previous case but which may or may not be comparable to the situation at hand.

The ionospheric problem for the radio operator is analogous to the weather problem for the pilot. Certain general situations are known and can be determined before a flight, but in both cases the operator must have a general knowledge of the dynamics of the subject in order to make decisions properly when the details do not turn out as forecast. The pilots have the weather problem in hand, the radio operators have yet to delve into the ionospheric problem.

Ionospheric disturbances do play havoc with medium and high frequency communications. Their effects are, of course, felt first and longest on circuits where power radiated along the communication path or the receiver antenna gain along the path is relatively low, such as is usually the case in communications with aircraft. We do not have the means of preventing these disturbances any more than we are able to turn off the rain or a thunderstorm. However, there are some means of minimizing the effects on communications. Fringe benefits are obtained by proper maintenance of equipment and by proper selection of communication frequencies. At the moment, we depend upon predictions prepared in advance. In the future we may be able to sample the ionosphere and make a better frequency selection on the spot, just as we use weather radar for seeing the latest in weather systems.

Disturbances are most severe at latitudes above about 45° and communication circuits which stretch along east-west paths are particularly sensitive. Considerable improvement and extension of communications time is possible by use of a ground relay station well to the south. An example of this is the use, for some years, of the Azores as a relay for aircraft flying the North Atlantic route. The distance from any point on the route is of the same order, so that a rather annoying variable is eliminated and one need only consider the usual variation of frequency with time of day.

The discussion now leads naturally to a situation where the relay point is overhead, i.e. a satellite.

The frequency ranges and systems problems involved are quite different from those discussed above. The system required may be thought of as equivalent to that required to track the satellite. It does not appear to be practical in the near future for aircraft communications.

CONCLUSION

It is apparent that HF communication, in spite of its limitations, remains the most suitable method for long range communication with aircraft.

By application of our present knowledge of the characteristics of the ionosphere, much can be done by the aircraft radio operator to improve communications.

It is worthwhile to pursue the possibility of using VHF meteor reflection communications. Use of satellites is still a thing of the future.

C.A.I. LOG

SECRETARY'S LETTER

HALIFAX-DARTMOUTH

THIS YEAR, for the first time, the President was planning to visit the eastern Branches and it was all laid on to take advantage of a tour which had been arranged by Mr. T. E. Fessenden of Grumman. Mr. Fessenden was going to speak to the Halifax-Dartmouth Branch on the 29th November and the Quebec Branch on the following day; and the President and I were going to accompany him. However things began to go wrong; the President had to go over to England at the critical time and Mr. Fessenden had to cancel his trip at the last moment because of bad weather. Somehow, the weather notwithstanding, TCA managed to get me round the course and I had a very enjoyable couple of days.

I had been at Shearwater, of course, only ten days before with the Test Pilots Section and it was good to be back so soon. This time we had quite a good Branch meeting in spite of the absence of both the President and the speaker; it gave me an opportunity to say a few words about the affairs of the Institute in general and to hear what the Branch had to say; then they ran a couple of films, produced miraculously at short notice, and, though we all missed Mr. Fessenden, we got by.

QUEBEC

There seems to be no way of getting from Halifax to Quebec (or vice versa) by air, without going via Montreal. It was raining in torrents at Halifax and the weather which had upset Mr. Fessenden's plans had upset the airlines generally. However by shifting flights I managed to make my connection at Montreal and reached Quebec on time, with the first snow of winter.

The Quebec Branch was even more ingenious than Halifax-Dartmouth in filling the gap left by Mr. Fessenden's cancellation. One of their own members, Mr. L. A. Dickinson, gave us a new form of talk; he ran through a few slides to provide background to an erosion burning phenomenon in rocket engines which he could not account for, and then asked the audience for advice. He got plenty and a most stimulating discussion ensued. I am not sure that we helped him much but I think we all learned a little. I can recommend this sort of meeting, particularly to Specialist Groups.

GROUPS

Speaking of Groups, I must mention the very excellent work being done by the Montreal Astronautics Group under Dr. H. J. Luckert's guidance. I cannot give details here but suggest that you look at some of his reports published in previous issues. So far as I know, Dr. Luckert works very closely with the Montreal Branch Executive Committee and the activities of his Group fit in harmoniously with the Branch programme. I wish we could get more of these Groups going elsewhere.

SHOW YOUR GRADE

In his address to the Annual Dinner last May, Mr. F. T. Wood, President of the AITA, referred to our grades of membership and urged Industry to take note of them, as giving "a broad indication of what a man is worth". Of course one of the purposes of joining a technical society is to establish a standing in one's profession. We should make use of this feature of our membership; we should get into the habit of using "initials after our names" in all our professional dealings. You will notice that we are adopting the practice of indicating the grades of membership of the authors of papers published in this Journal.

Under the terms of the Institute's Regulations, Honorary Fellows, Fellows, Associate Fellows and Members are entitled to use Hon.F.C.A.I., F.C.A.I., A.F.C.A.I. and M.C.A.I., respectively. Admission to any of these grades is contingent upon the member having attained a "recognized standing". No such qualification is necessary for admission to the other grades and therefore the use of such abbreviations as "T.M.C.A.I." and "J.M.C.A.I." is not permitted.

Those who are entitled to use these abbreviations of their grades ought to do so.

TEST PILOTS SYMPOSIUM

The Test Pilots Section held a Symposium at RCN Air Station, Shearwater, on the 18th and 19th November. The programme of technical sessions on the second day had to be changed to enable some of the visitors from out-of-town to leave early; the resultant crowding of all the work into the morning session left insufficient time for discussion and, in this respect, this part of the meeting – the symposium proper – was unsatisfactory. However the first day, which was spent aboard HMCS Bonaventure at sea, was a great success; moreover, since most of the visitors were accommodated in the Wardroom where they were in constant contact with one another and with the Navy pilots, they talked 'shop' from the moment they arrived until they went their several ways and a meeting has seldom been richer in terms of that intangible element, professional association.

Registration desk

HMCS BONAVENTURE

Most of the visitors arrived in the evening of the 17th November and were ready for an early start on the following day. In anticipation of bad weather which might have made it impossible to visit the carrier at sea, the local members of the Section had arranged an alternative programme at the Air Station; in addition, yet another programme at the Air Station had been arranged for any one who could not be accommodated on the visit to the carrier. As it happened the weather was perfect and everyone who was there in time could be taken aboard; nevertheless these precautionary programmes were very much appreciated – and looked so attractive that one wished the meeting could have been extended another day to include them.

The party of 26 left shortly after 8.00 am in six HO4S-3 helicopters and was taken to HMCS Bonaventure, which with her destroyer escort was operating about 20 miles offshore. She was carrying six Trackers and three Banshees. The weather was excellent, with a wind of about 35 knots and perhaps a 7 ft sea.

Immediately on arrival the visitors were conducted to various vantage points on the island to watch the flying operations. The ship had recently been in refit and one of the inevitable bugs developed in the catapult gear after two Trackers had been launched; the third Tracker was therefore lowered down the lift and the remaining three took off unassisted. The three Banshees were not launched. With unobtrusive resourcefulness, the party was taken below and shown a film while the catapult was being rectified. This film not only gave a general description of the ship and its operations but showed certain items, such as the operation of the submarine sounding equipment on the helicopters, which were not on the "live" programme. The film, with its accompanying cup of coffee, was a welcome interlude.

Then the party went back to watch the Banshees take off. The catapult is some 112 ft long, requiring from 3 to 5 g to launch a Banshee, and these launchings were a spectacular performance. But probably the approaches and landing of both Trackers and Banshees were more impressive. The Banshees in particular made several circuits and bumps before they succeeded in hooking an arrester cable. These passes at better than 100 knots, over a postage stamp heaving on a lot of ocean – and seen from close quarters – are not a sight that one forgets easily.

Duly humbled, the land-based test pilots retired to the wardroom for coffee and a short commentary by CDR W. H. Fearon, Commander (Air), HMCS Shearwater, which was followed by some keen questioning; this sort of flying was a new experience. After this, the party was split up into groups of 4 or 5 and taken on conducted tours of the ship. And so back to the wardroom for lunch.

The afternoon programme began with a short lecture about the catapult gear, delivered on the site, out on the flight deck, in the wind; thereafter the time was spent watching further flying. Two RCAF pilots went up in Trackers – and survived the experience, not noticeably greyer!

Four members arrived at Shearwater too late to visit the carrier with the rest of the party, but they were put in a Tracker and flown out to watch the afternoon's flying from the air. An Expeditor was also seen cruising around; it was flown by another member of the Section, who was later rather unfairly accused of being afraid to make an approach and landing!

One more comment about the ship, a small point perhaps compared with the spectacular flying, but worthy of mention. The skill with which the aircraft were handled on the flight deck was astonishing. Taxied with wings folding, they were parked in very tight formation; or, with wings unfolding, they were taxied out of

Helicopter airlift from Shearwater to HMCS Bonaventure

these tight formations under their own power, with hardly any handling by the flight deck crew.

And so back by helicopter to Shearwater.

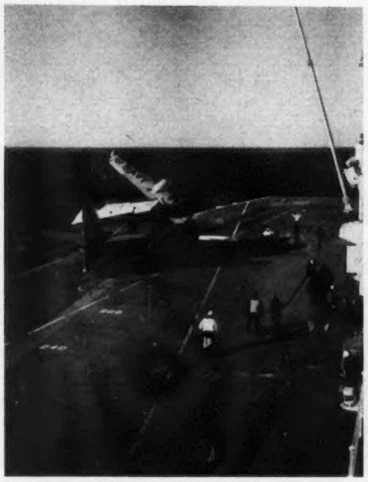
DINNER

The Dinner in the Wardroom of the Air Station was preceded by a Reception at 8.00 pm.

Mr. R. J. Baker, Chairman of the Section, was in the Chair, with LCDR G. M. Cummings, Chairman of the Halifax-Dartmouth Branch, on his left and Commodore W. M. Landymore, Chief of Staff, Flag Officer Atlantic Coast, the Principal Speaker, on his right. Other Head Table guests included Captain T. C. Pullen, Commanding Officer, RCN Air Station, Shearwater, and Mr. A. C. Earle, General Manager, Fairey Aviation Company of Canada. There were 60 members and guests present.

The Dinner was conducted according to naval procedure, adapted to suit the circumstances. Before and after the meal the Chairman called on CDR E. B. Morris and LCDR W. H. Frayn, respectively, to say Grace. When the meal was finished and cleared away, the port was ceremoniously passed and CDR Fearon was asked to propose the Toast to the Queen. The Chairman then asked LCDR Cummings to introduce the Head Table, which he did after saying a few words of welcome to the Test Pilots Section on behalf of the Halifax-Dartmouth Branch and the Station. This was followed by Commodore Landymore's address.

The Commodore's subject was The Development of Naval Aviation and he traced its growth from the initial flights of Eugene Ely in the USA in 1910 and Lt C. R. Samson, RN, in 1911 and 1912, through the Royal Navy's conversion of the liner Campania into the first real carrier in 1915, and up to the proud days of the allied fleets in the Pacific at the end of World War II. His touch was light and he included some entertaining anecdotes of his own and Captain Pullen's experiences in their Cadet days. He then turned to the changes that have taken place since the war, with the increase of the submarine threat and the consequent changing role of the carrier. He concluded with a reference to the Institute's name as an analysis of the word "aero-nautical"; command of the air over the sea was his closing definition of naval aviation.



Tracker taxiing up to the catapult

Mr. G. T. McLean, Vice-Chairman of the Test Pilots Section, thanked the Speaker and added his thanks to the Commanding Officers of HMCS Shearwater and HMCS Bonaventure for their great contributions to the success of this very successful meeting. His words were echoed by the Chairman who, in his closing remarks, thanked CDR Fearon and LCDR Frayn for their work in preparing such a satisfactory programme, and Mr. Kidd and Mr. Luttman, the Secretaries of the Section and of the Institute, respectively, for their coordination and organization. He also passed on a message he had received from Mr. Luttman expressing the President's regrets at being unable to attend.

At this point LCDR Frayn said that he had just received a message from the President, which he had been unable to pass to the Chairman; it read as follows:

Banshee takeoff from the flight deck

In the Wardroom before the Dinner
(l to r) Mr. H. C. Luttman (Secretary CAI), Mr. G. T. McLean (Section Vice-Chairman), LCDR G. M. Cummings (Branch Chairman), Mr. R. J. Baker (Section Chairman), Commodore W. M. Landymore (Principal Speaker), Mr. R. M. Kidd (Section Secretary) and Captain T. C. Pullen (Commanding Officer, RCN Air Station, Shearwater).

"Regret my enforced absence from your conference and festivities. Please convey my best regards to the gang."

With this the Dinner was adjourned.

THE SESSION

As mentioned above, it was decided to try to combine the sessions arranged for the morning and afternoon of the second day, the 19th November. Because it was planned to hold a lobster luncheon, with refreshments furnished by The Fairey Aviation Company, in the Hook Bar, the session was held in the TV Room of the Wardroom. An additional 17 members registered for the second day, making a total registration of 43. About 30 members attended this session.

The Three Papers

Mr. McLean was in the Chair and introduced Mr. R. J. Baker as the first speaker; Mr. Baker's subject was *Jet Transport Operation in Canada*

In his paper the speaker reviewed some of the new factors introduced into airline operations with the big jets, using TCA's experience to date as an example. He began by considering performance certification and some of the changes introduced with the jets, affecting takeoff, takeoff flight path and landing. He then spoke of flight planning and cruise control and the use of pre-computed data to guide the choice of procedure to meet conditions. In the training of pilots, TCA made extensive use of the simulator in view of the tremendous operating cost of actual flight. Airline operations at altitudes of 30,000 ft or more had introduced new problems in high altitude weather forecasting and the speaker made the point that accurate terminal forecasting was assuming new importance with the advent of the jet transport. After a brief discussion of noise problems, Mr. Baker concluded with a review of routine flight problems, in which fuel consumption appeared to be the governing consideration.

To open the discussion of this paper, the Chairman asked for further comments about the use of reverse thrust and the speaker explained that TCA never used reverse thrust in the air for let down because of the vibration, but used it on all landings. However its use was confined to the inboard engines because, if all engines were reversed, the exhaust gases from the inboard engines travelled forward and were ingested by the outboard engines, causing severe rumble.

The Chairman also asked if foot-thumpers were the only form of anti-skid device on the DC-8. The speaker replied that anti-skid brakes were also installed.

CDR Hunter asked if approach speed indicators were used. The speaker said that they were installed on the DC-8 but were still under review by the FAA, and therefore TCA only used indicated air speed at present.

F/L Lumsdaine asked for further particulars about the landing problem with respect to landing roll, landing weight and speed. The speaker replied that it was a requirement that the aircraft must be able to stop within 60% of the runway length and speed over a 50 ft obstacle must be 1.3 V_s. It followed that, if the aircraft weight was too great, it was necessary to burn off fuel to avoid excessive approach speeds. The problem could be more acute in winter on icy runways and the first winter's operations would have to be watched carefully.

W/C Christie asked about holding speeds. The speaker said that the requirement was 210 knots at landing weight and, though an attempt was made to reduce this speed by the use of flaps, much depended on fuel load and altitude, and the DOT was not happy if 210 knots was demanded. W/C Christie pressed the point and

The speakers: (l to r) Mr. F. C. Phillips, S/L G. H. Knight, Mr. R. J. Baker and Mr. G. T. McLean (Chairman)

asked what would happen if the DOT insisted on lower holding speeds; the speaker replied that TCA would then hold at 20,000 ft, which would solve the problem.

W/C Christie also asked about climb-out procedures. The speaker said that the DOT complained that TCA used too much space during turns but tighter turns produced too high a g for the passengers; this was still an unsolved problem.

The Chairman then introduced Mr. F. C. Phillips, whose subject was

Development History of the CL-41

The paper, which was illustrated by a film and slides, gave a complete review of the birth and development of the CL-41, including preliminary design, early wind tunnel spin investigations, which resulted in the T-tail, money problems, military liaison during design, mock-ups, the decision to prototype, further wind tunnel testing including wing stall characteristics, canopy design, safety features, the philosophy of compromise between fatigue requirements and cost of the prototype etc.

There was no discussion after this paper, because its presentation had taken longer than the time prescribed. After a short break, the Chairman introduced the last speaker, S/L G. H. Knight. S/L Knight's paper was entitled

Stability and Control Aspects of the CL-44

In this paper S/L Knight reported on the stability and control tests which had been done to date on the CL-44 by integrated RCAF-Canadair crews to CAR 4b requirements, the FAA criteria. Graphs of longitudinal stability including elevator angle, neutral points, manoeuvre points, stick force per g etc were shown and discussed. The speaker pointed out that certain portions of the flight envelope remained to be covered but in general results had been acceptable and no major problems were expected.

Mr. Baker opened the discussion with a question about behaviour of the aircraft during cross-wind landings. The speaker replied that tests and measurements up to 18 knots cross-wind had been carried out, with no difficulties.

To a question about roll rate the speaker replied that this had been checked satisfactorily for symmetrical flight; tests in asymmetric flight have yet to be carried out.

The Forum

At the conclusion of this discussion, Mr. McLean handed over the Chair to Mr. Baker, Chairman of the Section, who sat with Mr. McLean on his right and Mr. Kidd on his left at the rostrum.

Mr. Baker said that the Open Forum discussion would have to be curtailed in view of the change of programme and would have to be confined to considerations of the future activities of the Section. However before the discussion started Mr. Kidd read a message that he had received from Mr. W. K. Ebel, as follows:

"Regret unable to make Shearwater. Best of success for Symposium."

This message from Mr. Ebel, who was known personally by almost everyone present, was very much appreciated.

The discussion covered such topics as a proposal for a joint meeting with SETP – unfortunately Mr. W. S. Longhurst, who was the official representative of the SETP, was absent from the session at this point – possible extension of the Section's membership to include flight test engineers, the help that the Section might render to the Institute by the provision of speakers for Institute Meetings and some tentative thoughts about the next Section Symposium.

In adjourning the session, the Chairman expressed his thanks to The Fairey Aviation Company for their hospitality in the luncheon which was to follow.

Thus the Symposium ended and, after an excellent lunch, the members boarded their aircraft and went their several ways.

BRANCHES

Halifax-Dartmouth

Reported by F. T. Dryden

November Meeting

The regular meeting of the Branch was held in the cinema of the Chief Petty Officers' Mess, HMCS Shearwater, on Tuesday, 29th November. 59 members and guests were present. The Branch Chairman, LCDR G. M. Cummings, presided.

Those present were disappointed at the unavoidable absence of our President, Mr. David Boyd, and a further disappointment was in store because Mr. T. E. Fessenden, our guest speaker didn't say the right thing to the weather man, and was grounded in Boston.

Rallying to the emergency Mr. H. C. Luttman, our hard working Secretary, carried the flag.

Mr. Luttman first addressed the meeting in general terms and on branch affairs. He then said a few words on Man-Powered Flight. He spoke of the possibilities of man-powered flight, saying that a little research and experimenting in the subject could yield great possibilities. He stated that the idea of private flight had been strangely forgotten in the race for outer space, and the idea of flight for sport had accordingly been ignored, but man-powered flight, if people were willing, could be developed into a very keen sport. Although there had been some work done on man-powered flight, very little was known about low speed aerodynamics.

Mr. Luttman's talk was followed by a film, entitled "Man in Outer Space".

The Chairman thanked Mr. Luttman for rising to the occasion so valiantly at such short notice.

Secretary's visit to the Halifax-Dartmouth Branch
Back row: (l to r) Mr. V. W. Bowers, Mr. W. G. Stewart, Mr. F. T. Dryden, and CPO R. L. Sabourin
Front row: (l to r) Prof. O. Cochkanoff, Mr. H. C. Luttman, CDR W. H. Fearon, LCDR G. M. Cummings and CPO A. C. Green

Ottawa

Reported by Lt J. M. Vivian

November Meeting

The regular monthly meeting of the Branch was held on Thursday, 17 November, at the Montgomery Branch of the Canadian Legion. A total of 72 members and guests attended including a contingent of 10 officer cadets from RMC Kingston.

Mr. G. D. Watson, Chairman of the Branch, opened the meeting and called upon Mr. David Boyd, President of the CAI, to introduce the speaker, Mr. A. A. Lombard, Director of Engineering, Rolls-Royce Ltd., Derby.

The topic of Mr. Lombard's lecture was "Bypass and Fan Engines". He first detailed the design differences between the two engines, their respective advantages and limitations. It was established that, while the fan arrangement is readily adaptable to existing engine designs, the bypass engine has the advantage of a single jet efflux with attendant greater propulsion efficiency and simplification of thrust reversing mechanism, a smaller diameter and less intake noise.

Mr. Lombard next gave a short history of his company's jet engine development program. Using graphs he illustrated that the rate of increase of overhaul times is increasing for each new engine introduced. This is indicative of rapidly advancing improvements in materials and design. Graphs were also used to show the power output growth of various engines during their service lives and the increase of compression ratios to achieve greater economy. Mr. Lombard stated that the provision for this growth has become a major consideration when designing a new engine.

The factors governing the design and choice of materials for compressor and turbine blades were next covered by the speaker. Air cooled turbine blades, developed to enable the use of higher flame temperatures, were described and illustrated on slides.

Jet engine noise was dealt with in detail by Mr. Lombard. Acceptable noise levels were compared with those produced by aircraft now in service. Although aircraft such as the Comet and Viscount exceed these levels, the speaker stated that they have proven to be acceptable in service. An adequate reserve of power for rapid climb out away from built up areas was considered to be a contributing factor. It was the opinion of Mr. Lombard that the problem of noise reduction cannot be adequately solved by the use of suppressors and must subsequently be an important consideration in the design of future engines.

The speaker was thanked for a very interesting and informative lecture by Mr. M. S. Kuhring. Although Mr. Lombard's support of the bypass type engine proved to be most convincing it was generally felt that a lecturer from "that other company" should be invited at some later date to deliver a rebuttal in support of their choice of the fan.

Cold Lake

Reported by F/O D. N. Bailey

November Meeting

The monthly meeting of the Branch was held on the 17th November at RCAF Station Cold Lake.

The 8 members and 19 guests were welcomed by the Branch Chairman, F/L N. H. Smith, who then called on Mr. G. B. Jeffery to introduce the speaker of the evening, CDR J. F. Frank.

CDR Frank presented a well-prepared and absorbing paper, illustrated with a film and slides, on the aircraft equipment and ancilliaries and also the ship's equipment required for the operation of aircraft from ships. The talk covered both fixed and rotary wing aircraft.

Following CDR Frank's talk, there was a lively discussion which was finally called to a halt by F/L R. J. Cockburn, who thanked the speaker for a very interesting and informative presentation.

Calgary

Reported by F/O L. A. Flaherty

November Meeting

The November meeting of the Calgary Branch was held in the Al San Club, Calgary, at 8.00 pm on the 15th November. This was a dinner meeting, followed by a talk by a guest speaker.

In addition to the guest speaker, there were two other guests present, S/L Howie, Commanding Officer of RCAF Station Calgary, and Mr. R. Bell.

There were 18 members and 3 guests present.

Mr. J. M. Robertson introduced the guest speaker, CDR J. F. Frank, who spoke on Ship-based Aircraft. The speaker's talk was well supported by slides and film, and certainly got across to the members some idea of the specialized requirements necessary when designing aircraft for operation off ships. He stressed that the major threat is the submarine and the Air Force and the Navy must be prepared to fend against it. To this end the Navy utilizes Tracker, Banshee and Helicopter aircraft. With the introduction of faster aircraft, increasingly critical requirements are placed not only on the design of the aircraft, but on the carrier itself.

CDR Frank went into detail describing how the RCN gets their aircraft airborne and back on deck. He also took us below deck with some details of the design requirements for support of the aircraft, maintenance, repair etc. The Navy must be able to repair damaged aircraft as quickly as possible, in a minimum amount of space.

The introduction of the angled carrier deck has permitted great advances in the use of jet aircraft. CCA (Carrier Controlled Approach) and the use of steam catapults were some of the highlights covered by the speaker.

CDR Frank's talk was followed by an interesting question and answer period, at which time the speaker admitted that occasionally their AOG requirements had to be satisfied by the RCAF.

At the conclusion of CDR Frank's talk, Mr. Robertson thanked him on behalf of the Calgary Branch.

Calgary Branch Executive Committee
Standing: (l to r) Mr. J. M. Robertson, Mr. A. Bushell, Mr. J. D. Zmurchyk and Mr. W. E. Jamison
Sitting: (l to r) Mr. J. H. Stanley, Mr. G. H. Fenby and F/O L. A. Flaherty

Vancouver

Reported by M. G. Brechin

November Meeting

The November meeting of the Vancouver Branch was held on November 14th, 1960, at the RCAF Officers' Mess, Sea Island.

A short business session was conducted by S/L A. E. Falls, Vice-Chairman, in the absence of the Branch Chairman, Mr. F. L. Hartley.

The speaker for the evening was CDR J. F. Frank, Director of Aircraft Design, RCN.

CDR Frank's subject, "A Review of Technical Requirements for Operation of Aircraft at Sea", detailed the many and varied technical requirements of aircraft designs for operation at sea, of which the layman and public are not aware.

Detailed descriptions by the well versed speaker, outlined the many mechanical equipments necessary and the problems encountered in both design and operation. Films and charts showing the operation of the equipments necessary, such as folding wings, arresting gear, steam catapults and semi-automatic landing devices, supplemented the talk.

The efforts of the Navy are toward the sub menace. This menace is being handled by both fixed wing and rotary wing aircraft, the evaluation and upgrading of designs which, with all their associated technical problems, are a continuous demand producing new and challenging requirements.

The talk, one of the most interesting and comprehensive presented to the Vancouver Branch, was followed by a question and answer period. This period illustrated the interest which the group took in the talk by the scope and number of questions raised.

Toronto

Reported by K. A. Kinsman

November Meeting

The November meeting was held at The De Havilland Aircraft's cafeteria on Wednesday, 16th November, 1960, at 8.15 pm. Mr. D. J. Caple, Sales and Contracts Manager for Orenda Engines, who is the Chairman of the Propulsion Group of the Toronto Branch, was Chairman for this meeting. He welcomed 103 members and 75 guests to hear Mr. A. A. Lombard of Rolls-Royce, Derby. Mr. Caple introduced a special guest for the evening, the President of the CAI,

Rolls-Royce in Toronto
(l to r) Mr. B. A. Avery, Mr. A. A. Lombard, Mr. D. Boyd, Mr. C. H. Bottoms and Mr. D. J. Caple

Mr. David Boyd. Mr. Boyd said a few words on the financial and membership aspects of the Institute, indicating how important they are for the Institute's survival.

Mr. Boyd presented membership certificates to Mr. Wells and Mr. Bobrick, recent members of the Toronto Branch.

Mr. Caple called on Mr. C. H. Bottoms, Branch Chairman, to introduce the speaker. Mr. Bottoms extended the Branch's appreciation for Mr. Lombard's consent to come to Canada to give this lecture. Mr. Lombard is well qualified for such a talk since his experience with gas turbines goes back 20 years.

The present DC-8 and 707 jet transports have given quite a commitment to the engine manufacturers and provided competition which has benefited the aircraft manufacturers. The number of engines installed in the DC-8 and 707 is large and includes many versions of the J-75, JT3D-1 and the Conway. These various types have been installed in only 400 aircraft.

The Conway has been in service since the 1st April, 1960, and has a thrust of 17,500 lb. The Vickers VC-10 will use an increased thrust version of the Conway.

From this point Mr. Lombard illustrated his lecture with many slides.

The Pratt & Whitney JT3D-1 which is a ducted fan engine has high velocity air coming out of an annulus ahead of the compressor. The Conway ducts this air down an annular duct to the tailpipe. The advantages of the bypass can be summarized as follows:

(1) The mixing of the two gas streams at the tailpipe give more uniform temperature and velocity distribution for maximum energy and momentum change, and

(2) The engine is encased in cool air.

The installation of the ducted fan P & W JT3D-1 in the Boeing 707 was used as an example of how to minimize the drag penalties from the high velocity air jet ahead of the compressor. The pod arrangement by fixing the engine ahead and below the the wing causes minimum wing interference by this air jet. It is interesting to note that future projects by both Rolls-Royce and Pratt & Whitney include bypass engines only.

The relatively new Conway is scheduled for 50 DC-8's and 707's and 45 Vickers VC-10 and Super VC-10's. Since the 1st April, 1960, the Conway has reached 110,000 hours experience with the one million mark due by the end of 1962. The first month of airline service with Conways obtained more hours than in the engine's development program.

Hours between engine overhaul against years of service looks very promising for the Conway. The Dart engine has gone from 400 to 3,000 hours overhaul life or, at the present flying rate, one million miles between overhauls. The Avon used in the Comet and Caravelle has gone from 1,000 to 2,300 hours life in two years of operation. This is a steeper rise than the Dart's. The Conway, set initially at 1,000 hours, is now 1,200 hours after seven months' service. This has an even steeper slope than the Avon's.

The reliability of the Conway RC-12 after six months can be best illustrated by 1 engine shutdown for 6,000 hours and engine removals by all causes, 1 in 3,200 hours. It is interesting to note that these figures compare very favourably with a piston engine, although they can't yet compare with the Dart's or Avon's performance. The average time between removals is 940 hours, while a competitor's has only one-half engine life.

Aluminum compressor blades have shown their advantage over titanium and high tensile stainless steel blades. Notched blades duplicating as close

Some of those attending the November meeting

as possible service conditions show the following fatigue facts:

(1) Aluminum blades lose 36% of their strength,
(2) Titanium blades lose 65% of their strength, and
(3) Stainless steel blades lose 47% of their strength.

Another advantage of aluminum blades is a weight saving which is magnified many times when loads are traced to structure.

The inlet guide vane to rotor axial clearance has proved to be very important to the engine's tolerance to foreign object ingestation. The Conway has a very large gap of 3 inches.

A new Rolls-Royce engine RB141 is a bypass engine similar to the Conway, but having a 2-stage turbine. This engine has been designed from experimental work and correlation of all design data from past engines. A turbine efficiency of 91½% has been obtained, and the bypass pressure ratio has been set as high as possible without penalizing compressor efficiency.

Several slides followed showing the RB141 mounted in a test cell and on an engine cradle. It is interesting to note that in a bypass engine the accessories don't dictate the housing profile.

A cyclic test is used to shorten the time required to find out the condition of parts after a specified number of hours' service. The cycle used is 0% to 95% thrust in 5 seconds, remain at 95% for 95 seconds and then 95 to 0% thrust in 5 seconds. The RB141 has gone through 1,500 cycles of this cyclic test with no damage to components. The turbine blades which are air-cooled by internal passages have proved to have decided advantages. Air-cooling means higher turbine operating temperatures and Rolls-Royce is the first manufacturer to have ¼ million hours on this type of blade. By 1963, it is expected to have 3½ million hours of service with air-cooled turbine blades. Other manufacturers won't have this blade type until 1963.

A recent meeting of the Montreal Branch Executive Committee

(l to r) Mr. C. D. Garbutt, Mr. C. M. Newhall, Mr. C. L. Bernier, W/C H. J. M. Londeau, Mr. D. O. Stapleton, Mr. D. R. Taylor, Mr. H. G. Farish, Mr. R. J. Conrath, Dr. H. J. Luckert, Mr. R. J. Chadborn and Mr. S. Bernstein.

Several slides were shown illustrating temperature patterns and thermal shock results on air-cooled blades. In both cases great improvements are evident. Rolls-Royce philosophy is to find the best material available and then air-cool. In 1953 the maximum turbine temperature was 1560°F. By 1965 a turbine temperature of 1832°F is expected.

A problem which still requires much development is noise. The Conway has 100 hp of noise in the jet. A motor car horn has 1/15 hp for comparison. A present noise suppressor only halves the noise energy; this is 12 db in 125, and it requires an expert to detect this change. The De Havilland 121 reduces jet noise by using low jet velocities and hence high bypass ratios. At 2½ miles the DH 121 jet noise is a maximum of 100 db.

Intake noise will become objectionable when jet noise is reduced. It is of the order of 115 db which is just a bit less than the present 707 and DC-8 jets. Intake noise can be reduced by choking the intake, thereby causing sonic velocities which can't transfer the noise forward. A choked intake can give a 10 db reduction. The next serious noise source is from the turbine, caused from wakes at the blades' trailing edges and from the passage of blades past the stators.

The 707-120 has a very bad noise problem in the takeoff and climb out condition mainly due to its poor climb performance. The Comet because of its high rate of climb has proved to be better. Height above ground is considered the best noise suppressor.

In conclusion, Mr. Lombard stressed the fact that while a bypass type engine would be used on future supersonic aircraft, the new short haul, low cruise speeds, short field performance aircraft would use a ducted fan engine with very high bypass ratios (2.5:1).

A lively discussion followed before Mr. B. A. Avery, Vice-President and General Manager of Orenda Engines, thanked Mr. Lombard for his excellent talk. Mr. Caple adjourned the meeting at 10.45 pm.

MEMBERS

NEWS

K. H. Larsson, A.F.C.A.I., has been appointed Vice-President–Sales in charge of commercial sales for all areas other than the North American continent for Canadair Ltd.

A. J. Lilly, A.F.C.A.I., formerly Director of Sales with Canadair Ltd. has been appointed Assistant to the President.

I. M. Liss, A.F.C.A.I., formerly with Litton Industries Ltd. is now Chief Electronic Engineer, Aircraft Division, The De Havilland Aircraft of Canada Ltd.

J. A. Morley, A.F.C.A.I., is now Vice-President–Sales, Canadair Ltd., in charge of all commercial sales on the North American continent.

P. H. Redpath, A.F.C.A.I., has retired from his position as Vice-President –Sales at Canadair Ltd.

R. F. Copley-Tanner, M.C.A.I., formerly with Avro Aircraft Ltd., has returned from England to take up the position of Chief Design Engineer with Canadian Applied Research Ltd.

T. G. Dunkin, M.C.A.I., has been appointed Assistant Manager, Sales Engineering, Canadair Ltd.

M. C. Eames, M.C.A.I., has returned to Dartmouth, N.S., from the United States to take a position with the Naval Research Establishment.

S/L E. E. Erhart, M.C.A.I., has been transferred to Brookley Air Force Base, Alabama, for a period of two years as Production Control Officer in the Aircraft Branch.

G. C. Keefer, M.C.A.I., formerly Director of Contract Administration has been appointed Vice-President–Administration at Canadair Ltd.

C. E. B. McConachie, M.C.A.I., has been appointed Assistant (Sales) to the Executive Vice-President.

V. V. R. Symonds, M.C.A.I., who was General Manager, Bristol Aero-Industries Ltd., Ottawa, is now Contracts Manager, Litton Systems (Canada) Ltd., Ottawa.

J. Ferguson, Technical Member, has recently been appointed to the Quality Control Division, Electronics Branch of Flight Test, Canadair Ltd.

J. Godden, Technical Member, has taken a position with Okanagan Helicopters Ltd., Toronto.

W. J. C. Slade, Technical Member, has moved to the United States to take up the position of Manager of Renner Inc., College Point, New York.

R. B. D. Wright, Technical Member, has recently taken a position as an Associate Engineer with the Boeing Airplane Co. in Seattle.

C. F. Fincham, Associate, has been appointed Vice-President–Military Relations at Canadair Ltd.

DEATH

It is with deep regret that we record the death on the 31st December of the **Rt. Hon. C. D. Howe, Hon. F.C.A.I.**

ADMISSIONS

At a meeting of the Admissions Committee, held on the 24th November, 1960, the following were admitted to the grades shown.

Associate Fellow

Dr. D. H. Henshaw, Special Projects Engineer, The De Havilland Aircraft of Canada Ltd., Downsview, Ont.: *21 Hernshaw Crescent, Etobicoke, Ont.*

Mr. J. Wood, Vice-President and General Manager, Rolls-Royce of Canada Ltd., Box 1400, St. Laurent, Montreal, P.Q.

Member

R. P. Blake, Superintendent, Mechanics Wing, CARDE, P.O. Box 1427, Quebec, P.Q.: *2921 Providence Ave., St. Foy, Quebec, P.Q.*

G. Haigh, Engineer – Dart Engine, Trans-Canada Air Lines, Winnipeg, Man.: *690 Croydon Ave., Ste. 11, Winnipeg 9, Man.*

Prof. H. E. T. North, University of Manitoba, Winnipeg, Man.

COMING EVENTS

IAS

29th-31st January, 1961 – *30th Annual Meeting,* HOTEL ASTOR, NEW YORK.

CAI

27th-28th February, 1961 – *Mid-season Meeting,* WINNIPEG, MAN.

BRANCHES

Tour Speaker

Lubricant Qualification Tests and Facilities at the NRC, DR. R. B. WHYTE
17th January – Calgary
18th January – Cold Lake
19th January – Edmonton

Ottawa

15th February – *Navigation System for a Mach 2 Transport,* W/C K. R. GREENAWAY.

Halifax-Dartmouth

25th January – CPO's MESS CINEMA, *Rocket Propulsion,* MR. L. A. DICKINSON, HEAD, ROCKET ENGINE DEVELOPMENT, CARDE.

Edmonton

14th February – *Development of the Douglas DC-8,* G. L. FARQUHAR, ASST. CHIEF PROJECT ENGINEER–DC-8, DOUGLAS AIRCRAFT.

Vancouver

16th January – RCAF OFFICERS' MESS, SEA ISLAND, *Panel Discussion on Constant Frequency versus Frequency Wild Generating Systems for Aircraft.*

February – *Joint CAI/SAE Meeting.*

Note

The Editor would welcome details of forthcoming meetings of other societies which would be of interest to members of the Institute.

BOOKS

REVIEWS

Advanced Aero Engine Testing. Edited by A. W. Morley and Jean Fabri. Pergamon Press, New York, 1959. 298 pages. Illus. $9.00.

It has been apparent from the earliest days of the aircraft gas turbine, that exhaustive component testing is essential for the development of an efficient, stable engine. More recently, the necessity for simulating the high altitude, high Mach number, flight environments has been realized. Advanced Aero Engine Testing is a collection of ten papers presented to the AGARD Joint Meeting of Combustion and Propulsion, and Wind Tunnel and Model Testing Panels at Copenhagen in October 1958. Most of these papers are comprehensive, up-to-date reviews of at least one broad segment of the propulsion system testing field. Consequently the book might be considered an essential addition to any institutional Propulsion or Aeronautical library.

Part 1 contains four papers that give a fairly well co-ordinated review of types of engine altitude test facilities and propulsion system wind tunnels, their potential uses, and their problems. E. J. Manganiello of NACA's Lewis Flight Propulsion Laboratory outlines many representative propulsion system problems that can be investigated most fruitfully in a full scale altitude test facility, and describes the types of test facilities that have proven adequate to handle each type of problem. B. H. Goethert of ARO Inc. concentrates on the methods of simulating engine inlet distortions encountered in flight, and methods of accomplishing transient condition testing on propulsion systems. Problems in control of the test facilities during engine transients and problems in separating propulsion system transient response from test facility response are dealt with.

Hensel and Matt of ARO Inc. review the features and capabilities of most of the major wind tunnels and altitude test facilities available in NATO countries. They describe in considerable detail the layout and capabilities of the Propulsion Wind Tunnel at Arnold Engineering Development Centre, Tullahoma, Tennessee.

Marcel Pierre of ONERA describes the large facility at Modane. Unfortunately this paper is printed without translation from its original French, as are many of the discussions on the other papers. The reviewer feels that the value of the book would have been greatly increased had the trouble been taken to obtain English translations.

The second part of the book contains five papers dealing with the testing of engine components.

Smith and Payne of Rolls-Royce Ltd., Derby, describe their company's turbine and compressor test rigs used for scale model tests. A discussion of scale effects and some general conclusions from their experience on these rigs provide helpful (though not new) information for engine designers.

Lefebvre and Halls of Rolls-Royce present an extremely valuable review of combustion chamber scaling theory and experiment. Their experience indicates that they are able to offer simplified scale relationships that omit some of the complex terms appearing in recent theoretical studies of the problem.

An excellent paper by Cockshutt, Levy, and Sharp of the National Aeronautical Establishment, describes the turbine blade temperature measurement technique, developed for flight tests of an Orenda 14 engine fitted with an NAE designed afterburner using fuel to splash-cool the turbine blades.

Gabriel and Wallner of NACA Lewis Flight Propulsion Laboratory discuss the inter-relation effects of engine components. Examples are given of the effects on compressors, combustors and turbines of inlet temperature and pressure distortions.

Two other papers complete the book, one by Macioce of the Italian Air Force on parameters used in turbojet performance analysis, the other by Pryor of General Electric Company on supersonic engine flight test development.

R. M. Sachs

Property Measurements at High Temperatures. By W. D. Kingery. John Wiley & Sons, Inc., New York, 1959. 416 pages. Illus. $16.50.

No matter what type he may be, the engineer who is concerned with the application of metals at high temperatures, or who is dealing with the more sophisticated refractory metals or cermets for use at higher temperatures, must, of necessity, ask two questions, "What are the properties at the particular temperature in which I am interested?" and "How accurate has been the method of determining these properties?"

In this book, W. D. Kingery not only discusses preferred methods for determining such properties as heat conductivity and radiation, density and thermal expansion, strength, elasticity, viscosity and electrical and magnetic properties, all at temperatures above 1400°C (2500°F), but he includes a large number of sketches which make his descriptions much easier to follow.

In his introduction, the author states that it was not his intention to compile a laboratory manual, but he has succeeded admirably in doing so; the chapters dealing with Laboratory Refractories and Furnaces, for example, include valuable data on the engineering properties of many of the refractory materials which are finding their way into rocket engines and nose cones, where re-entry problems are posing certain difficulties.

It is somewhat thought-provoking to find that plasma-arc furnaces are capable of developing temperatures up to 15000°C, and although at present they can only be regarded as very high temperature sources, not furnaces for property measurements, these are certainly tremendously high temperatures and will undoubtedly be harnessed some day.

Probably the most interesting facet of this book is that it deals not with just one method of performing property measurements of each different type, but details alternative methods and lists their advantages and disadvantages. Numerous references are provided at the end of each chapter and the reader is urged to make use of these before undertaking laboratory work, so that he may be fully informed as to the optimum experimental technique for the determination of the specific property and the precautions that must be adopted to ensure accuracy of results.

R. Smallman-Tew

Statistical Theory of Communication. By Y. W. Lee. John Wiley & Sons, Inc., 1960. 509 pages. Illus. $16.75.

As stated in the preface, this book is intended for first year graduates in electrical engineering. The objective, which the author has achieved with excellent organization of material and meticulous attention to detail, is to convey an appreciation for a statistical approach to the solution of problems associated with the communication of data. It is assumed

that the student is familiar with the application of advanced calculus to problems involving harmonic analysis.

The author enters his subject with a discussion based on the extension of the Fourier theories as applied to random functions, carrying the student through this phase on a broad front with excellent choice of illustrations. Following this review, the statistical analysis concept is expounded from Chapter 3 onwards, the author applying the theories of probability upon which subsequent studies are based. The author maintains a broad coverage without excessive extension throughout the remainder of the 19 chapters supplying sufficient introductory material at every stage

This book is not only recommended for the post-graduate student wishing to rigorously pursue the subject of waveform analysis but also the design engineer, not necessarily the communications engineer, requiring a sophisticated reference text.

W. R. M. McLellan

Aircraft Engines of the World 1960-61. By P. H. Wilkinson. Paul H. Wilkinson, Washington, 1960. 288 pages. Illus. $15.00.

In reviewing the latest volume of this series, it was satisfying to record the new arrangement of illustrations and detailed data confining each engine to the space of one page. This process of compression has permitted the inclusion of many more engines, while maintaining the convenient over-all book size, without sacrifice of detail or clarity.

Although the data tabled for each engine is adequate, for most reference purposes, this writer considers there would be real value in having the aircraft applications of each engine included. This would not require excessive space and adds a very useful piece of information for those interested in determining the success and potential of an engine. With this provision, the status of the engine could be conveyed simply by use of the words development or production as appropriate.

The first page of the book has been devoted to a picture of a large afterburning gas turbine mounted in a test cell. The test bed situation appears to symbolize the absence of aircraft applications for the large engines of today. Several of the engines, despite the advanced stage of development reached, are still without firm commitment to an airframe. With engines of this calibre the aircraft manufacturer, intent on producing a supersonic transport, will be spared the anxiety associated with parallel powerplant developments.

An interesting and accurate dissertation, of all the engine manufacturers of the world, has been included to highlight the production and development engine achievements of the past year. From this it becomes evident the wider application of the gas turbine is due to the concentration of effort in the small and medium power class plus the emphasis on the turbofan, by-pass and ducted fan engines. Still persistently sharing a place of prominence in the aircraft field, the reciprocating engine retains a sizeable portion of the book; including the appearance of thirteen new versions.

As has become customary, the current edition briefly summarizes the progress in the nuclear aircraft programs. A further step, in keeping abreast of the times, has been taken by allocation of a small section to the liquid propellant rocket jets. Rocket propulsion, of this nature, has successfully been demonstrated in research aircraft and as an augmentation power system for conventional aircraft.

In summary this book remains a reliable source of engine data. This status has been maintained through continued progress in phase with the engine developments of the world. As such this edition warrants a position in close proximity to the many engineers and operators interested in the engine aspect of aviation.

W/C W. R. Cole

MAN-POWERED FLIGHT LIBRARY

Listed below are some of the recent acquisitions to the Man-Powered Flight Library.

Books and papers are available on loan to members of the Institute free of charge and to non-members at 25c per item per week or part thereof. Those wishing to borrow them should address their requests to the Secretary, indicating how long they are likely to need them.

Flight by Man-Power – Guerra, E., and Gunther, B.

Comments on Dr. Wilkie's "Work Output of Animals: Flight by Birds and by Man-Power"", Nature 183, 1515 (1959). Considerations of mechanical similarity, electrodynamical similarity and biological similarity leading to a suggested specification for a man-powered flying machine.

Man Powered Flight in 1929 – Lippisch, A. M., J. of the RAeS, Vol. 64, No. 595, July, 1960.

As ornithopters were favoured for man-powered flight in Germany in 1929, the author describes an experimental vehicle with flapping wings built by himself and A. Schleicher. Details and sketches of construction are given as well as photographs of the aircraft in flight. Tests are described, with H. W. Krause as pilot. Unfortunately details of the test flights were never published. The author concludes with recommendations for building a similar aircraft in the light of present knowledge.

Man Powered Aircraft Committee (MAPAC), Aims and Constitution – Cranfield.

Design and Construction of a Full Scale Ornithopter – Fitz Patrick, J. L. G.

Natural Flight phenomena are investigated by gross observation, dissection and study of past science and art. A complete hypothesis in the closely related area of bird-bat function and structure is formulated. Small scale analogs are devised and tested; a large scale analog is designed and built for testing. Includes a short illustrated history of previous attempts in this field and a summary and evaluation of the results so far attained; and a commentary on the literature on the subject.

Goodyear Airmat Fabric – Goodyear Tire and Rubber Co., Akron, Ohio.

Describes construction of Airmat fabric and its use in building an inflatoplane. Sample of Airmat fabric and a photograph of the inflatoplane are included.

Human Muscle-Powered Flight – Unsolved – The Problem of Leonardo da Vinci – Raspet, August, Soaring, May-June 1952, Vol. 16, No. 3.

Reviews the possibilities of achieving human muscle-powered flight in the near future. Recent advances in structures and aerodynamics give definite indication that human muscle-powered flight should be possible within 500 years of the birth of its inventor, Leonardo da Vinci.

Silver Wing Aircraft Co. – Crain, J. A.

Photograph, Certificate and statement regarding an ornithopter in Maine.

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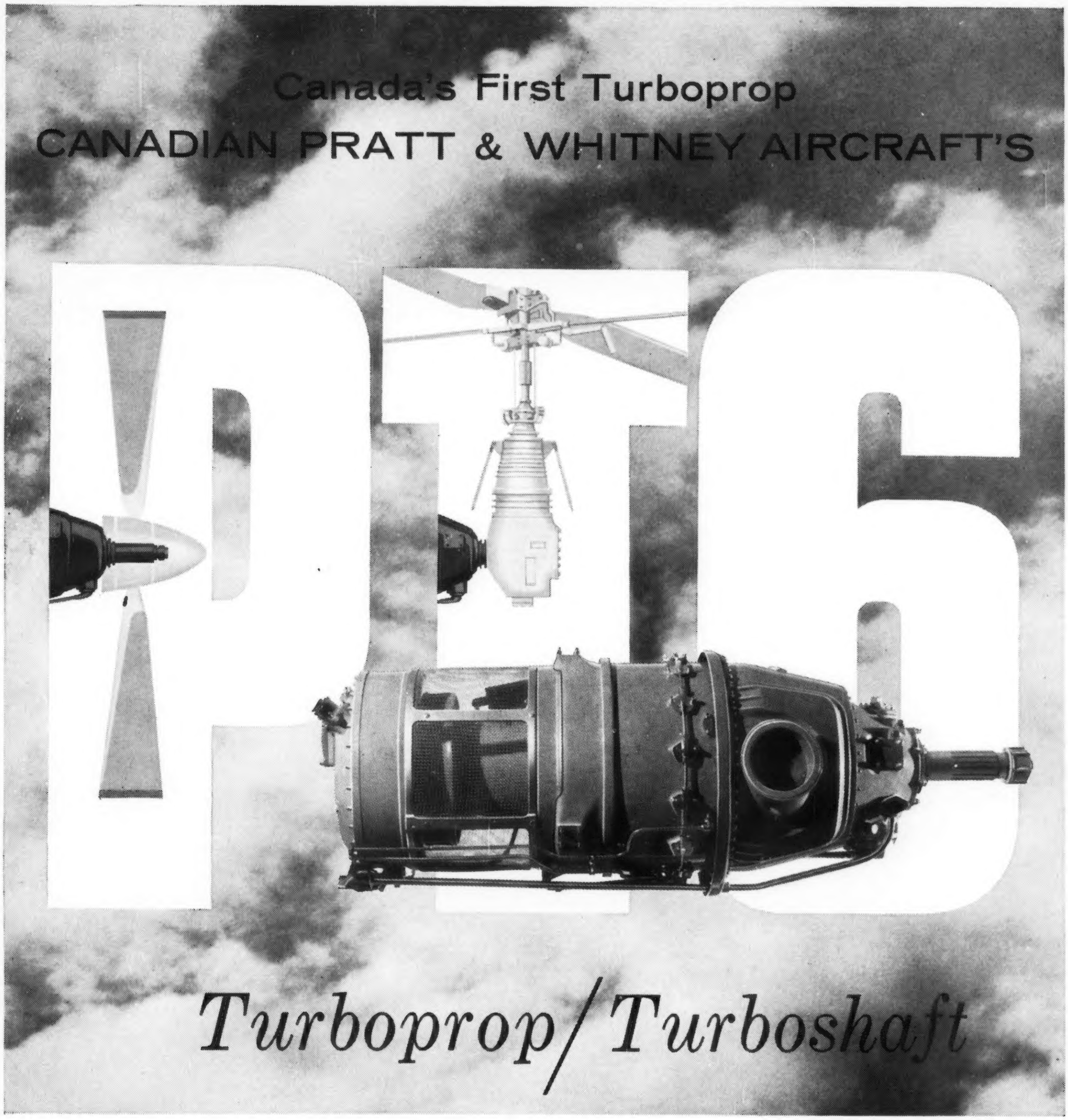
APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No. to which enquiries may be addressed (c/o The Secretary) will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.



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Available in 1961 from: *Canadian Pratt & Whitney Aircraft*

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A subsidiary of United Aircraft Corporation, East Hartford, Conn.

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